

PAPERS FROM THE THIRD INTERNATIONAL SYMPOSIUM
ON THE SILURIAN SYSTEM:
THE SIR FREDERICK MCCOY SYMPOSIUM

INTRODUCTION

THE THIRD International Symposium on the Silurian System was held as part of the Palaeontology Down Under congress in Orange, New South Wales. The congress, organised by the Macquarie University Centre for Ecostratigraphy and Palaeobiology, was attended by 122 participants. A broad spectrum of research themes was explored in five symposia, several of which have resulted in published collections of papers (Talent & Mawson in Laurie, 2002).

The Silurian Symposium paid tribute to Sir Frederick McCoy (c. 1823–1899), an illustrious natural historian, in recognition of his decisive role in delimiting the Silurian and documenting its fossils. The present collection of papers was presented at the Symposium or explores relevant themes in Silurian–Devonian palaeontology.

McCoy's role in the great Cambrian–Silurian debate of the 19th Century and his pioneering work in recognising the Silurian in Australia are the focus of a paper by Doug McCann and Neil Archbold. They recount how McCoy's palaeontological research in Britain provided the breakthrough that allowed Sedgwick's Cambrian System to conclusively be distinguished from Murchison's all-encompassing Silurian. As a professor at the University of Melbourne and later as Director of the National Museum of Victoria, McCoy made major strides in demonstrating that the geological time scale developed in Europe was applicable in Australia and is, indeed, a global phenomenon.

The Silurian rocks of Victoria were scrutinised by McCoy and his colleagues at the then newly-founded Geological Survey. The complex tectonic history of the Victorian Silurian succession remains a lively field of study. John A. Talent and coauthors present conodont faunas from carbonate units in the Silurian of eastern Victoria, and explore the chronological and tectonic implications of these new data. The precise temporal framework provided by the conodonts contributes to resolving whether several controversial limestone units are allochthonous or autochthonous, as well as setting constraints on the duration of the Benambran Orogeny in its type area.

Carlton E. Brett and David C. Ray present a case study in sequence and event stratigraphy for the Silurian in North America that will serve as a model for field-based sequence stratigraphic studies in other parts of the world, including Australia. Their paper draws correlations between the well-exposed Llandovery and Wenlock units in the Cincinnati Arch and coeval strata in the Appalachian Basin of New York and Ontario. Broad-scale regional correlations of sequences and their bounding surfaces, integrating event beds and biostratigraphy, suggest that eustatic sea level controls the development of sequence boundaries over a broad geographic extent on the Laurentian craton.

Frederick McCoy was highly regarded for his monographic taxonomic treatments of Australian Palaeozoic fossils. James Valentine's taxonomic study of Early Devonian brachiopods from the Buchan Group of eastern Victoria carries on this tradition (indeed, the first palaeontological work on the Buchan limestones was undertaken by McCoy himself). Valentine documents 35 species of brachiopods from the Murrindal Limestone, one of the richest Devonian brachiopod faunas in eastern Australia. The taxonomic composition of the silicified Murrindal faunas is most similar to Emsian faunas from the Taemas–Wee Jasper area of New South Wales.

I am indebted to John A. Talent, who inspired our colleagues to contribute excellent papers for this volume.

Gregory D. Edgecombe

TALENT, J.A., & MAWSON, R. 2002. Preface. In *Palaeo Down Under Conference. Papers from the conference held at Kinross-Waloroi School, Orange, New South Wales, July 2000*, Laurie, J.R., ed, *Association of Australasian Palaeontologists, Memoir 27*.

FREDERICK MCCOY AND THE SILURIAN SYSTEM

DOUG MCCANN¹ & NEIL W. ARCHBOLD¹

¹ School of Ecology and Environment, Deakin University, Melbourne Campus,
221 Burwood Highway, Burwood, Victoria 3125

MCCANN, DOUG & ARCHBOLD, N. W., 2005. Frederick McCoy and the Silurian System. *Proceedings of the Royal Society of Victoria* 117(2): 151–173. ISSN 0035-9211.

The foundation of the Silurian system in 1835 by Roderick Murchison and the subsequent publication in 1839 of his monumental work *The Silurian System* (along with its accompanying map) is generally recognised as a landmark in the progress of global stratigraphy. The physical structure, composition, fossil content and stratigraphical order of these previously obscure Lower Palaeozoic strata were now made manifest and thus available for correlation within Great Britain and Continental Europe and, eventually, worldwide. Murchison's Silurian system was rapidly accepted by the majority of geologists as the major period of the Lower Palaeozoic. Murchison's triumph, however, brought him into conflict with his former friend and collaborator Adam Sedgwick who accused him of overextending the lower boundary of the Silurian and encroaching on geological territory which was rightly part of the Cambrian system. In 1835 Sedgwick had proposed the Cambrian system directly following Murchison's declaration of the Silurian system. The Cambrian-Silurian debate escalated into one of the longest running and most bitter disputes in 19th Century geology.

Irish-born Frederick McCoy, who published *The Silurian fossils of Ireland* in 1846, later became embroiled in the Cambrian-Silurian debate while working as Sedgwick's palaeontological assistant. It was McCoy who established that Sedgwick's Cambrian system contained its own distinct fossil assemblages and could justifiably be separated out from Murchison's all encompassing Silurian. Following his emigration to Australia in 1854 McCoy recognised the Silurian and Cambrian locally, and then went on to validate the presence of other major European systems, such as the Cretaceous and the Devonian, along the length of the geological column. McCoy was therefore the first to confirm unequivocally that the geological column was a coherent global entity.

Keywords: Lower Palaeozoic, Silurian, Stratigraphy, Cambrian

IN 1839 Roderick Murchison (1792–1871) published his monumental work *The Silurian System*, one of the most significant geological publications of the 19th Century. As well as launching the Silurian system as a pivotal stratigraphical unit in the Palaeozoic Era it helped confirm Murchison's status as one of the world's most pre-eminent geologists. Murchison's global influence in geology is difficult to overestimate. He was the founder of the Silurian system, founder of the Permian system and with Adam Sedgwick co-founder of the Devonian system. His Silurian system rapidly received international acceptance. Frederick McCoy (c. 1823–1899; Figs. 1, 2 herein) was a young man when Murchison published *The Silurian System* but as he gained experience and insight as a novice palaeontologist he was suitably awed by Murchison's achievement. Under Adam Sedgwick's tutelage he later came to question some of Murchison's interpretations. McCoy, in fact, made the vital breakthrough which led to a reconsideration of the evidence of just where the lower boundary of the Silurian period lay and paved the

way for the recognition of a legitimate and distinct Cambrian period as Sedgwick had long advocated. This key insight was a first step in an eventual resolution of the debate. McCoy went on to play a leading role in the correlation of the stratigraphical periods in Australia, including the Silurian, with corresponding European and North American units.

The Silurian period as defined in the early 21st century is a greatly reduced entity in comparison with that delineated by Murchison in the mid 19th century. It is now the shortest period in the Palaeozoic Era, covering a span of some 28 million years (International Commission on Stratigraphy 2004, from Gradstein et al. 2004) — about half that of the other major periods which are all in the vicinity of about 50 million years duration. At its zenith in the 1840s Murchison's Silurian system included everything below the Devonian down to the top of the basement rocks of the 'Azoic' (or in modern terms the Precambrian) — amounting to about 150 million years duration or about half of the Palaeozoic Era. In retrospect, Murchison's fear that if he compromised



*Very truly Yours
Frederick McCoy*

on Stone by F. Schoenfeldt.

Hamel & Co. Lith. 79 Queen St.

Fig. 1. Lithograph of Frederick McCoy by Frederick Schoenfeldt, signed by Frederick McCoy; from a series entitled 'Notable Men of our time'. Published by Hamel and Co., c. 1859. La Trobe Picture Collection, State Library of Victoria.

on the extent and boundaries of his Silurian system his hard won geological territory would be in grave danger of becoming "attenuated" proved to be well founded. Within a few years of Murchison's death the suggestion was made by Charles Lapworth that a new period, the Ordovician, be substituted in the place of his Lower Silurian (Lapworth 1879). This proposal gradually gained international acceptance and Murchison's once vast Silurian was whittled down to its present size.

The establishment of the Silurian system by Murchison and of the broader ordering of the stratigraphical rock sequence as a whole was one of the major achievements within geology in the 19th century. Murchison's demarcation of the Silurian rocks was a milestone in the development of stratigraphical palaeontology especially in its application as an indispensable aid to geological mapping. Some notion of the rapidity with which the Silurian system was adopted throughout Europe is indicated by its inclusion into Grigori Petrovich Helmersen's Geological Map of European Russia in 1841 (Hecker 1987). Murchison clashed with Sedgwick on, among other things, the issue of fossils versus lithology as being satisfactory and sufficient indicators of a geological period. Frederick McCoy, who was just beginning to establish himself as a capable palaeontologist at this juncture in the late 1830s, later became involved in the debate and provided further evidence that fossils, if available, can indeed be definitive indices for the demarcation of the geological time scale, just as Murchison was arguing. Nevertheless, it was Sedgwick rather than Murchison who benefited most from McCoy's palaeontological work.

McCoy's early career in Ireland

Little is known of Frederick McCoy's early education (Darragh 2001: 160). There is also some uncertainty about his exact date of birth; however, he later testified several times that he developed an interest in natural history at a very young age. He was only a young teenager when he published his first paper — on ornithology, for which he retained a life-long interest. The paper was titled 'Remarks on Mr Eyton's arrangement of the Gulls' (McCoy 1838), published in the *Magazine of Natural History*. Typically for McCoy his initial paper addressed some of the finer points of biological classification and nomenclature. In 1839 he joined the Geological So-

ciety of Dublin and began to specialise in the study of fossils. He was appointed assistant to Dr John Scouler one of the Society's secretaries and helped arrange the fossil collections in the Society's Museum (Griffith 1841). As Darragh (2001: 160) notes, Scouler, who was a noted naturalist and Professor of geology, zoology and palaeontology at the Royal Dublin Society, must have been an important early influence on McCoy. It was also in 1839 that McCoy published his first paper on fossils. He described a Carboniferous ostracod and named it after his mentor *Entomoconchus scouleri*.

His work for the Geological Society of Dublin required him to curate and arrange the fossil collections of the Museum. In 1841 he arranged for sale the Henry Charles Sirr collection of shells and fossils as well as curating the collections of the Geological Society of Dublin and the Royal Dublin Society. In addition, by this time McCoy was also deeply involved in palaeontological work for Richard Griffith (1784–1878) who was primarily responsible for the production of the first complete geological map of Ireland. McCoy was commissioned by Griffith to work on the extensive Carboniferous Limestone fossil collections made by Griffith and his staff of the Boundary Survey of Ireland. Griffith needed these fossil determinations to establish the relative ages of sedimentary strata for the compilation of his Geological Map of Ireland. McCoy described some four hundred and fifty new species of fossil organisms. After some delay the results were published in a monograph in 1844 as *A Synopsis of the Characters of the Carboniferous Limestone Fossils of Ireland*.

An examination of the list of the fossil descriptions included in McCoy's book on the Carboniferous indicates the scope of his abilities at a relatively young age (Archbold 2001). Fossil phyla covered included (in modern taxonomic terms) Cephalopoda, Gastropoda, Bivalvia, Conulata, Brachiopoda, Trilobita, Ostracoda, Annelida, Echinodermata, Coelenterata and Bryozoa. Obvious also is McCoy's talent as a natural history artist. Archbold judges that "his illustrations of new species were also of exceptional quality for their time". They were drawn as realistically as possible, usually showing the imperfections of the specimens and less simplified than, say, Phillips (1836, 1841) or less idealised than, say, de Koninck (1842) or those of other comparable authors of the time. It is significant that von Zittel (1901: 451) in his *History of Geology and Palaeontology* remarks that the publications of de Koninck, Phillips and McCoy

were 'still the basis of all European research on the faunas of the Carboniferous limestone'. McCoy's works are still regarded as being classic contributions to palaeontology (as, for example, his contributions on the study of Palaeozoic corals (see Ivanovskii 1973)).

Further work for Griffith carried out by McCoy resulted in a second book *A Synopsis of the Silurian Fossils of Ireland* published in 1846. Seventy new species were included and as with the previous book about 12 phyla were described in total. As Archbold (2001) notes, McCoy possessed an exceptional knowledge of the earlier and contemporary palaeontological literature of both British and continental European workers. Adam Sedgwick, who first met McCoy while on a visit to Dublin in 1841, later said of McCoy that "no one of my friends...has so large an historical knowledge of foreign works on Palaeontology".

During his work on the Irish Silurian McCoy became thoroughly acquainted with Roderick Murchison's research and thinking. Of necessity, one of the main reference works McCoy consulted was Murchison's authoritative *Silurian System*. Griffith had delayed publication of the *Silurian Fossils of Ireland* in the hope that he would have the opportunity to write a description of the geology of the collecting localities. Unfortunately this expectation was not realised and in the meantime Murchison and colleagues published his second major opus *Geology of Russia* which included details of the Silurian geology and fossils of Russia, the latter largely by de Verneuil. This forced Griffith to instruct McCoy to revise his already completed fossil determinations. Griffith explained this situation in his introduction (or 'Notice') at the beginning of the *Silurian Fossils of Ireland*:

"The following Synopsis of Fossils collected by me from the several Silurian districts of Ireland, was completed by Mr M'Coy in the month of May, 1845, but its publication was delayed, in the expectation that, in the intervals of public duty, I should have had the leisure to prepare a Memoir descriptive of the Geology of the several localities, and thus render the work more perfect and useful. Unfortunately, I have been disappointed in this expectation, and, in consequence, have determined to print it in its present form. In the interval which has elapsed between the completion of the Synopsis and the present time, Sir Roderick Murchison's splendid and admirable Work on the Geology of Russia has ap-

peared, and with it the labours of M. de Verneuil and Count Keyserling on the Palaeozoic Fossils of Russia, &c., many of which occur in the Irish deposits. At my request Mr M'Coy has revised his Manuscript, and introduced the improvements in nomenclature proposed and adopted by those distinguished Palaeontologists" (Griffith, in McCoy, 1846).

In 1845 the Geological Survey of Ireland was established under Captain Henry James as the Irish Local Director. James was accountable to Henry De la Beche who as Director General of the Geological Survey of England and Ireland issued a set of instructions on the type of observations that were to be made in the field (Herries Davies 1983: 127). McCoy was the first field-surveyor appointed to the Irish Survey. James hoped to utilise McCoy's already significant palaeontological experience for the determination of the fossils collected by the Survey's Irish staff but De la Beche insisted that they should be sent to London for examination by the palaeontologist Edward Forbes (Darragh 1992). In lieu of doing fossil determinations McCoy instead was sent out into the field and was responsible for the production of some of the Irish Survey's very first maps. Many years later in 1889 giving evidence to a Royal Commission on Coal for the Victorian government, McCoy recalled:

"Yes, I was a member of the Imperial Geological Survey, and made in the field the geological maps of several counties, entirely by myself, for the British Government, according to the methods of the Imperial Geological Survey, which is considered the best in existence; and then, from a very early period of my rather long life, I have devoted myself to a branch of geology [i.e., Palaeontology] which I found people had not sufficiently acquainted themselves with...and before coming to this colony I had already established myself as an authority upon that branch of geology..." (McCoy 1891)

It might seem from the above quotation that during the early period referred to McCoy was happily engaged in field-work and mapping activities but this was far from the case. This was a troubled period for McCoy. Unfortunately for McCoy, Henry James who was pleased with McCoy's work resigned in 1846, and he was replaced by Thomas Oldham (1816–1878) with whom McCoy had previously quarrelled at meetings of the Geological Society of Dublin. Oldham had criticised McCoy's work on the fossils of the

Carboniferous and McCoy had vigorously defended himself. Aware of this antagonism, James, as one of his last actions as Local Director wrote to De la Beeche stating that '...it is clear that Oldham's appointment as Local Director, makes McCoy's position particularly unfortunate, and I should think it would be advisable to remove him to England.' De la Beeche, however, for whatever reason chose to ignore James' advice.

Oldham, who later moved on to a distinguished career as head of the Geological Survey of India, was soon chastising McCoy for numerous errors, omissions and careless work. This, incidentally, was not the first time McCoy had been accused of shoddy work. In 1842 he had lost his position at the Geological Society of Dublin because of alleged neglect of his curatorial duties. At that time he was deeply involved with his work for Richard Griffith and this may have left him open for criticism (Darragh 2001: 161). Oldham had been McCoy's successor as curator of the Geological Society of Dublin. Under Oldham's supervision at the Irish Survey, McCoy's position became increasingly untenable. Following James' departure McCoy attempted to find alternative employment and applied for several jobs but was not successful.

It is difficult from this distance in time to judge the relative merits of the accusations by Oldham against McCoy but in making an assessment several points need to be considered. Firstly, there was undeniably considerable hostility between them which probably coloured the issues. Secondly, as Herries Davies (1983: 142) points out, 'One of McCoy's problems in 1846 may have been that he was inadequately briefed as the duties of a field-geologist. De la Beeche's *Instructions* of May 1845 had been singularly unhelpful in this respect'. This problem was compounded by the fact that James himself seemed to have little idea of what was necessary. Herries Davies (1995: 34) comments that, 'One must, nevertheless, have some sympathy with McCoy. Neither he nor any other of the Survey's officers, would seem to have received any clear instruction from James as to the nature of their duties.' Thirdly, James had hired McCoy hoping to draw upon his palaeontological skills. McCoy had similar expectations himself. He was much more oriented towards the identification and classification of fossils than field mapping *per se*. Nevertheless, despite McCoy's difficulties during this period they seem to have had little negative impact on his future career.

McCoy at Cambridge University

In an attempt to extricate himself from his predicament at the Geological Survey of Ireland, McCoy wrote to Adam Sedgwick (1785–1873) the Woodwardian Professor of Geology at Cambridge University, who at that time was in need of a palaeontologist. Sedgwick was impressed with McCoy, later stating that, '...when I first saw him (in 1841) he had nearly completed his volume on the Carboniferous Fossils of Ireland. His Irish works put him in the front rank of British palaeontologists' (Sedgwick and McCoy 1855: xvi). In November 1846 Sedgwick wrote back to McCoy and offered him employment. He was invited to arrange the collections in the Woodwardian Museum at Cambridge. Sedgwick was confident that McCoy would be equal to the task. Commenting on his first interactions with McCoy, Sedgwick recalled that,

"When my friend formed his first engagement with this University, he came amongst us young indeed in look; but, even then, a veteran in Palaeontology. He was well trained and ready for the task he had undertaken; and far better stored with a knowledge of the foreign standard works on Palaeontology than any man with whom I had before conversed" (Sedgwick 1855: xvi).

The Woodwardian Museum housed a large collection that was originally established by a bequest by John Woodward (1665–1728) more than a century earlier. The original collection had been added to considerably over the ensuing years, including many specimens collected by Sedgwick and his students over three decades. Sedgwick also supplemented and expanded the collection by the purchase of other geological collections and selected individual specimens to develop one of the finest geological museums in the world (Rudwick 1975: 276).

Initially Sedgwick could only offer McCoy guaranteed employment for one year but this was extended to three years so that he could complete his arrangement of the Museum's palaeontological specimens, both British and foreign. In total they collaborated on the project for nearly eight years; for the first three years McCoy worked fulltime, then part-time. In 1849 McCoy was appointed to the Foundation chair of geology and mineralogy at Queen's College Belfast. His duties included responsibilities as Curator of the Museum, but he continued to travel back to Cambridge to work on the collections during vacations. Sedgwick reported that McCoy approached his work with

enthusiasm and "almost incredible labour and perseverance" (Sedgwick, quoted in Darragh 1992: 17). To give some idea of the extent of McCoy's work, Sedgwick, quoting from the Cambridge University Commission's *Blue Book* of 1852, remarks on McCoy's work on Count Münster's fossils — just one of the collections held by the Woodwardian Museum — as follows:

"Some notion may be formed of the greatness of his task when it is stated, that Count Münster's duplicates amount to more in number than 20,000, and that they form but a minute fraction of the great Palaeontological series Professor M'Coy has now arranged stratigraphically in the Museum" (Sedgwick 1855: vii)

Sedgwick further testified that towards the completion of the project "Professor McCoy was employed upon the Collection, not only during long hours of the day, but frequently during the late hours of the night" (Sedgwick 1855: viii). Initially released in three parts (McCoy 1851, 1852, 1855) this work on the British Palaeozoic fossils was collectively published as *A Systematic Description of the British Palaeozoic Rocks and Fossils in the Geological Museum of the University of Cambridge* (1855), a comprehensive and significant work in the history of palaeontology. One of McCoy's contemporaries, Professor Heinrich Bronn of Heidelberg welcomed the book as "one of the most important appearances in the literature of Palaeontology" (Fendley 1969: 134), and as Sedgwick remarked in the Introduction, "Whatever may be the merits of the following work, it is one of enormous labour."

It is clear that Sedgwick was very pleased with McCoy's contribution, describing him as "one of the very best palaeontologists in Europe". However, it was not just McCoy's important and wide-ranging contribution to systematic palaeontology, or his dedicated work in organising the collections in the Woodwardian Museum, that elicited Sedgwick's fulsome praise — he had another much more personal reason to be grateful to McCoy. For a number of years before he hired McCoy, Sedgwick had been locked in an increasingly frustrating and bitter geological dispute with his former friend and collaborator, Roderick Impey Murchison. Because of his association with Sedgwick, McCoy also, incidentally, and probably reluctantly, became involved in the debate, but nevertheless played a decisive role in its eventual resolution.

The Development of Stratigraphy in Britain

By the beginning of the 19th century in Britain it was generally accepted that the earth's rock strata were more or less in regular order as suggested by a variety of indicators such as lithology, mineralogy, morphology and organic remains. With the founding of the Geological Society of London in 1807 the organisation and order of the rock strata became a major focus for British geologists. Indeed, as a number of authors have pointed out (for example, Porter 1977: 181), most British geologists in the early to mid 19th century were stratigraphers or in some way supporting stratigraphical activities. At this time the term 'geology' became virtually synonymous with 'stratigraphy'.

Following the publication of William Smith's geological map of England and Wales in 1815 and George Bellas Greenough's improved version in 1820 considerable attention was placed by the members of the Geological Society on gathering more comprehensive and reliable geological data from all over Great Britain. Geological mapping of the rock sequences in Britain began in earnest in the early 1830s chiefly due to the work of Henry De La Beeche, who was appointed as first director of the Geological Survey of Great Britain in 1835, and work accelerated in the 1840s as the number of staff members of the Survey increased.

A parallel and necessary development that accompanied the production of useful and accurate geological maps was the growing understanding that 'organic remains' or fossils were critical indicators in determining the relative age and order of the stratigraphical rock sequences. In the early years of the development of the science and art of stratigraphy, it was lithology and geological structure that were the chief criteria in the recognition of major rock units and therefore of geological time units — for example, the term 'Jurassic' was applied to strata that corresponded to the Jura limestone; similarly, 'Cretaceous' for the chalk beds, 'Carboniferous' for the Coal Measures, and so on — however it became progressively apparent that many sedimentary rock units contained recognisable and distinct fossil faunas and floras and these could often be used to unambiguously determine the order of succession and relative ages of the strata. As a result, palaeontology increasingly came to be appreciated as an essential practical tool in geological mapping.

The use of fossil organisms for the elucidation of the age and order of sedimentary rock sequences

is known as *biostratigraphy* or *stratigraphical palaeontology* and its establishment as a sub-discipline within geology was an important step in the development of a number of related fields such as historical geology, sedimentology, economic geology and evolutionary biology. Zittel (1901) provides an early authoritative account of the history of stratigraphy. Other useful references include Berry (1968) and Gohau (1990). A succinct but inclusive article on the development of the Geological Time Scale is given by Branagan (1998).

Adam Sedgwick

One of the most important early contributors to the mapping of Britain's rocks was Adam Sedgwick (1785–1873), who was elected as Woodwardian Professor of Geology at Cambridge University in 1818. Although Sedgwick must have had at least a passing interest in geology as evidenced by his attendance at a meeting of the Geological Society of London in 1816 (Speakman 1982: 56; Woodward 1907: 39) his formal training and experience in the subject were minimal prior to his election. Trained in the classics and mathematics and ordained in 1817 he was favoured for the post as Professor of Geology more for his general academic and personal qualities than for any specialised geological knowledge he may have possessed at that time. Nevertheless, from the outset he embraced his new role with keen anticipation and zeal. He became a fellow of the Geological Society of London and carried out his first geological excursion in the summer of 1818 (Rudwick 1975: 275). The following year he began a course of lectures on geology which proved to be popular, influential and enduring. This celebrated lecture series was repeated annually until 1870; a period of over fifty years.

Sedgwick soon made up for his lack of experience and expertise in geology by familiarising himself as far as he was able with all aspects of the discipline. Within a few years he was presenting and publishing noteworthy papers and also developed a reputation as a superb field geologist. He was president of the Geological Society of London from 1829 to 1831, and of the British Association when it held its first meeting at Cambridge in 1833. Perhaps reflecting his mathematical background Sedgwick is reported to have had an uncommon ability to visualize and reconstruct geological structures and sequences based on specific but limited information

such as strike and dip measurements, jointing patterns, bedding planes and cleavage. He also had a capacity for translating local field observations into a broader regional context. This ability was early indicated when in 1822 he set about deciphering the dramatic and geologically complex rocks of the Lake District. It was in that year he first met William Wordsworth with whom he developed a warm friendship. They carried out many joint excursions into the Cumbrian Mountains. Sedgwick's *Letters on the Geology of the Lake District*, possibly his most well-known and widely read composition (Speakman 1982: 64), was later published along with Wordsworth's *Guide to the Lakes* in John Hudson's *Complete Guide to the Lakes* in 1842.

Sedgwick took an early interest in geological questions associated with lithology and stratigraphy. He was particularly influenced by the work of William Conybeare, one of the founders of systematic stratigraphy. In 1822, William Conybeare and William Phillips published their *Outlines of the Geology of England and Wales*, a handbook that summarised the stratigraphy of England, as it was then understood — from the recent unconsolidated sediments in eastern England to the base of the Old Red Sandstone in the west. This book helped lay down the foundations of English stratigraphical geology and influenced the direction and content of both Sedgwick's and Murchison's subsequent research.

Abraham Werner had earlier, by the 1790s, firmly established the concept of geological succession as the basis for the science of geology as it was then conceived. Werner subdivided the geological column into three principal sequences or 'formations', i.e., Primitive (or Primary), Secondary and Tertiary. He later added a fourth subdivision, the 'Transition' sequence, to denote an obscure and somewhat ambiguous series of rocks between the apparently unfossiliferous Primary rocks and the Secondary rocks which were usually layered and fossiliferous. The Primary, Secondary and Tertiary rocks in general seemed relatively straightforward and accessible for study, but the Transition rocks were somewhat of a mystery. The Transition rocks were usually layered or stratified but generally highly deformed, and even though fossils were known to be present they did not appear to be in great abundance. The opportunity for unravelling the true nature of this as yet poorly elucidated sequence beckoned for any aspiring ambitious geologist. There was the added attraction that it was then assumed that somewhere in the Transition sequence

the exact point at which life began might be discovered. Sedgwick and Murchison decided to take up the challenge by attempting to decipher the Transition rocks in southwest Britain.

Roderick Impey Murchison

Murchison, like Sedgwick, became a leading figure in nineteenth century geology (Stafford 1989), and eventually eclipsed Sedgwick in status. His earliest most important influence was William Buckland, professor of geology at Oxford University. Murchison was seven years Sedgwick's junior and actively cultivated a relationship with him; he benefited considerably from Sedgwick's geological knowledge and experience. Highly focussed and intensely ambitious, Murchison eventually outgrew his mentors to become one of the most influential scientists of modern times. He achieved this by hard work and a strategic research campaign — and also by securing membership and leadership of important scientific societies such as the Geological Society of London that he joined in 1824 and served as president from 1831 to 1834 and again from 1841 to 1843. He was a co-founder of the Royal Geographical Society and was its president for many years, enabling him to become a principle player in colonial science and exploration (see Stafford 1989). This dominance was further enhanced when he became director general of the Geological Survey of Great Britain in 1855 following the death of De la Beche. Murchison's influence eventually extended around the globe — including not only the British Empire but also Europe and North America.

Collaboration

Murchison's collaboration with Sedgwick began in the latter half of the 1820s; they conducted field trips to Scotland (1827) and the French Alps (1829) and published lengthy memoirs in the *Transactions* of the Geological Society. In 1831 they turned their attention to the relatively unknown Transition rocks of southwest England and Wales. The Transition rocks mainly consisted of thick confusing sequences of slate and the coarse dark sandstone known as greywacke. Greywacke is grey-coloured, poorly sorted sandstone ('dirty sandstone') consisting of quartz and feldspar grains and broken rock fragments mixed with substantial amounts of clay parti-

cles. Most of these Transition rocks were folded, faulted and altered.

To make sense of the Transition sequence was potentially a huge task so they decided upon a division of labour. Sedgwick would tackle the older primary and apparently lower Transition slaty rocks of North Wales. Murchison on the other hand decided on an approach from Western England into Wales from the southeast and would tackle the upper Transition sequences which were less disturbed and, as he discovered, more fossiliferous. For several field seasons they systematically devoted themselves to the task. Working cooperatively, but separately, they were soon satisfied that they were studying two different but contiguous geological 'systems'. By 1834 they felt that each had identified and interpreted the major structural, lithological and palaeontological features of their respective regions. So, in that year they spent four weeks together on their first, and what turned out to be, their only, joint field trip on the Transition rocks, in order to work out how the two systems meshed together and precisely where the common boundary might be.

Although the 1834 field trip was comparatively brief and a few issues remained unresolved, the two co-workers were confident that they had done enough work to clearly delineate two discrete geological systems and the joint boundary between them. Consequently, in 1835 Murchison designated his section as the 'Silurian' system, after an ancient British tribe that had inhabited the area. Sedgwick followed soon after with the name 'Cambrian' for the lower section after the Roman name for Wales. In August 1835 Murchison and Sedgwick presented a joint paper before the British Association for the Advancement of Science titled *On the Silurian and Cambrian Systems, exhibiting the order in which the older sedimentary strata succeed each other in England and Wales*. Both geologists were justly proud of their achievement. They were aware that their success in unravelling the structure and order of succession for the Lower Palaeozoic rocks in Britain would likely have global ramifications.

Interlude: The Fossil Plants of Devon

Even as Murchison and Sedgwick presented their findings on the Transition rocks in 1835, however, a complication had already arisen which loomed as a potential threat to their proposed classification. Just prior to their announcement of the establishment of

the Silurian and Cambrian systems, Henry De la Beche, in December 1834, reported that he had discovered fossil coal plants in Devon, supposedly of Carboniferous age, in the greywacke rocks (Rudwick 1985: 93). Sedgwick and Murchison were alarmed by De la Beche's report because it appeared to contradict their claims that the greywacke strata they themselves were studying were more ancient, and below the Carboniferous, with probably different plant types, if any at all. They felt sure that De la Beche was wrong and in 1836 they went out to investigate the area for themselves. They were able to establish that the coal bearing rocks were indeed above the greywacke and almost certainly did belong to the Carboniferous. However, the strata of rocks just below the coal bearing ones were intriguing and captured their attention because they appeared a bit different from anything else they had examined before. Because of their lithological form these rocks were initially thought to be Cambrian, but unlike Sedgwick's strata in North Wales which were relatively deficient in fossils, the rocks in Devon included many limestone beds and contained numerous fossils that had no apparent affinities with the Cambrian. Likewise, Murchison was reasonably sure they were not Silurian although there did appear to be some similarities between some elements of the two faunas. Another feature of these rocks was that the Old Red Sandstone was absent, whereas to the north, in Wales and the adjacent counties in England, it was present — in some places thousands of feet thick — and occupied a position below the Carboniferous but above the Silurian.

The controversy simmered for several years but in 1837 moved towards resolution following the suggestion by William Lonsdale — who was an expert on corals from the Carboniferous (or 'Mountain') limestone and had also worked on the Silurian corals — that in his opinion the disputed fauna was intermediate in character between the Carboniferous and the Silurian. In effect, the disputed fauna came from rocks that were apparently a marine sequence equivalent to the non-marine Old Red Sandstone in other areas of England and Scotland. At first there was some hesitation by Sedgwick and Murchison in accepting this explanation but after further study, including a field trip to Germany and Belgium in 1839, they came to the view that what they were dealing with was a distinct fauna in its own right and gave it the name 'Devonian'. This verdict was notable because it rested primarily on the fossil evidence rather than the lithology. This was the first

time that priority had been given to fossils in defining a major new geological system.

Publication of The Silurian System

Murchison, in particular, was determined to defend and promote his and Sedgwick's interpretation of the Transition rocks, or at least Murchison's version of it. In his introduction to *The Silurian System* (1839: 6) Murchison indicates that he initially intended to publish his results as a memoir in the *Transactions* of the Geological Society (Thackray 1978: 63; Bassett 1991: 20). As early as 1834 arrangements were made with the London publisher John Murray for the production of a separate treatise. A prospectus was issued and subscribers were sought. It took until 1839, however, before the project could be brought to completion. The result was a massive work, possibly three times the size originally planned (Thackray 1978: 64). *The Silurian System* was one of the most significant geological publications of the nineteenth century. By any measure it was an outstanding production. It was a hefty two-volume work, 820 pages in length, with a large folding accompanying map bound separately. It was also liberally illustrated with 112 wood engravings in the text and 14 scenic plates, three of which were hand coloured. In addition, in the second volume titled "Part II. Organic Remains" there was included 31 plates of fossils plus 9 hand-coloured fold-out copper plate engravings of geological sections. The palaeontological volume was essentially an edited work with contributions from J. de C. Sowerby and John Salter (shells, including the molluscs and brachiopods), Louis Agassiz (fish), William Lonsdale (corals) and Murchison himself with Charles Stokes (trilobites). Other minor contributors included John Phillips (encrinites), W.S. Macleay (annelids), Milne Edwards ('nondescripts'), W.J. Broderip (bivalves), and C. Koenig and H.H. Beck (graptolites).

The text was comprehensive, authoritative and accessible — but most of all it was a rationale for Murchison's Silurian system and a testament to his rise to dominance in world geology and palaeontology. Murchison's Silurian system with its characteristic invertebrate fauna rapidly gained acceptance in Europe and North America. The book was dedicated to Sedgwick but in hindsight it was a dedication that probably became more of an embarrassment to Sedgwick than a tribute — particularly as Sedgwick failed to produce a similar magnum opus despite repeated promises to do so.

The publication of *The Silurian System* made public for the first time differences of interpretation in exactly where the boundary lay between the Cambrian and Silurian. Sedgwick was surprised to find that certain areas that he and Murchison had formerly agreed were Cambrian were now claimed by Murchison to be Silurian. Initial polite disagreement over these relatively minor regions eventually escalated into one of the major geological disputes of the nineteenth century — mainly because Murchison in his publications progressively annexed more and more of Sedgwick's Cambrian strata until little remained. To employ a military metaphor (which Murchison loved to do), we could say that what began as a border skirmish ended up as open warfare and a strategic grab for territory.

The Cambrian–Silurian Conflict

Privately and publicly, argument and counter-argument took place in this protracted and rather complicated debate over the next two decades. Murchison, however, steadily and inexorably gained the ascendancy in the debate. Early in his geological career Murchison was impressed by the importance and efficacy of fossils in determining the age and order of the rock strata (although in this he had to rely on the skills of palaeontologists such as Lonsdale, Phillips, Sowerby and Salter rather than on his own determinations). While he recognised that lithology was important, Murchison over the years became increasingly conscious of the potential of fossils to define uniquely and correlate different rock strata. His confidence was strengthened when he discovered that with a bit of dedicated fieldwork Silurian rocks could be found that contained a recognisable and distinct fauna. Sedgwick, by contrast, like the majority of geologists, such as Aveline, Ramsay, Selwyn and others of the Geological Survey, believed in the primacy of lithology as a basis for identifying and delimiting the stratigraphical sequence. Sedgwick viewed fossils as a secondary tool, and certainly useful when other methods are unavailable, but believed that they should not be relied upon as the primary instrument in stratigraphical analysis. In his 1831 presidential address to the Geological Society of London he pointed out:

"Organic remains often help us to associate disconnected base lines. They also help us subdivide the successive deposits of an epoch, in areas where all other means fail; and in specu-

lating on the former condition of the earth they are invaluable; but they can in no instance supersede the necessity of study in detail of the structure and superposition of the great mineral masses covering the surface of the globe" (Sedgwick 1831; Speakman 1982: 78).

Even though Sedgwick regularly collected fossils on his field trips he admitted that although he knew many of them "by sight" he did not always know them by name (Speakman 1982: 78). Many of the fossils he collected remained unpacked and unsorted in the Cambridge Woodwardian Museum. Sedgwick was also at a disadvantage in the debate in that he was unable to establish an unequivocal distinct fauna in the apparently less fossiliferous Cambrian rocks. Instead he emphasised the immense thickness of the Cambrian strata. But as Murchison later declared: "...was the Cambrian system ever so defined, that a competent observer going into uninvestigated country could determine whether it existed there?" (Murchison 1852: 176; Berry 1968: 87). Murchison did indeed have a point; while geologists could positively identify his characteristic Silurian fossils anywhere they occurred around the globe, the best that could be said of Sedgwick's system was that it was a local entity that may or may not have implications outside his study area in Wales. Murchison was free to claim that Sedgwick's system was merely an earlier extension of the Silurian, and he did just that. By 1842 Murchison was asserting that on the basis of the evidence gathered up until that time it now appeared that Sedgwick's Upper Cambrian fossils were identical with his own Lower Silurian fauna. Only a small section of unfossiliferous rocks remained of Sedgwick's original Cambrian.

Sedgwick argued long and hard over the ensuing years in order to save his system. He carried out more fieldwork, he examined new areas and re-examined old ones, he put forward a number of new schemes, he invented new terminology and he was even willing to drop the name Cambrian altogether; however at this stage of the dispute he made limited progress in winning converts and convincing others of the merits of his ideas. As a result of Murchison placing more and more emphasis on fossil evidence to justify his system Sedgwick was forced to take the palaeontological aspect of the work much more seriously.

In 1842 he employed a young palaeontologist, John Salter, part-time, to help process the now vast collection of fossils he had accumulated over the years. Salter also accompanied him on a number of

fieldtrips to North Wales collecting fossils in an attempt to clarify the palaeontology and possibly even discover a discreet but simpler fauna than the Silurian, although by this time Sedgwick had virtually given up any hope of finding enough distinctive species (Secord 1986: 116). Even though they discovered some new fossils, there were not enough to constitute a system distinct from the Silurian. The remainder of the fossils collected were Lower Silurian types, which by now Sedgwick had come to expect. Salter made a promising start on cataloguing the Woodwardian Museum collection but soon left for full-time employment at the Geological Survey of Great Britain. This again left Sedgwick with the need for the services of a palaeontologist. The job was offered to a grateful Frederick McCoy who was relieved to be able to remove himself from the difficult circumstances he found himself in under Thomas Oldham's supervision in Ireland. McCoy's task was to complete the work that had been started by Salter.

McCoy and Murchison's 'Caradoc Sandstone'

McCoy, like Salter before him, arrived at a critical stage in the Cambrian–Silurian debate. McCoy conscientiously applied himself to the task of processing and determining the fossils in the Woodwardian Museum but also inevitably became involved in issues related to the disagreement between Sedgwick and Murchison. It should be noted that by the time of McCoy's arrival at Cambridge in 1846 it was not just Murchison and Sedgwick who had examined the Transition strata in question. By 1841 professional geologists of the official Geological Survey of Great Britain, who had just completed mapping of the coalfields of South Wales, began mapping in the area under dispute. John Phillips, one of the Survey's palaeontologists, reported that, in the Caradoc formation which was located towards the bottom of Murchison's Upper Silurian system, there were occasional anomalies, particularly in the Malvern Hills, in which Lower Silurian fossils would be found mixed with Upper Silurian (Phillips 1848). Everyone involved in the debate, including Sedgwick, believed that the Caradoc Sandstone was a coherent set of so-called "passage beds" positioned between the Silurian and the Cambrian which therefore could feasibly contain an intermediate or a mixed fauna. McCoy, however, probably alerted by the Malvern Hills anomalies reported by Phillips (Bassett 1991: 31) began to suspect that possibly

there were two different faunas involved, in deceptively conformable beds, but which appeared to be one lithological unit. Consequently McCoy, in the summer of 1852 was moved to conduct a review of the Caradoc faunas.

On examination of Caradoc fossils from a number of different localities McCoy found that they did separate out into two quite different groups — from some localities the Caradoc fossils had affinities with the Upper Silurian, from other localities the Caradoc fossils had affinities with the Lower Silurian (Murchison's Lower Silurian being roughly equivalent to Sedgwick's Cambrian). This strongly suggested the presence of a previously undetected unconformity within the Caradoc Sandstone. If McCoy was correct, then Sedgwick finally had a decisive and convincing way of splitting the Transition strata into two natural systems. Sedgwick was not willing to publicly announce these findings until he had confirmed them by examination of the Caradoc rocks in the field. In mid 1852 McCoy accompanied Sedgwick on a brief, rain-interrupted field trip which only allowed them to examine systematically the rock sections at May Hill and the Malverns, but that was enough to confirm McCoy's findings and vindicate Sedgwick's claims for a separate Cambrian system.

In November 1852 Sedgwick triumphantly presented his results in a paper to the Geological Society. Sedgwick asserted that he was able to justify subdividing the former Caradoc formation into two new groups; the upper part he named the May Hill Sandstone, the base of which Sedgwick designated as the base of the Silurian; for the lower part he retained the name Caradoc, this he designated as the top of the Cambrian. The fossil gap between the Cambrian and the Silurian on this evidence was much greater than the break between the Silurian and Devonian that Murchison had so strongly advocated; in fact, it proved to be one of the larger breaks in the whole of the fossil record. Sedgwick's explanation also correlated well with similar findings in Palaeozoic strata in central Europe and North America.

The reaction to Sedgwick's presentation by the members of the Geological Society was one of either stunned disbelief or grave scepticism. At first they could not accept that the professional geologists of the Geological Survey would not have realised or noticed that such a large geological and palaeontological divide existed between the two proposed systems. However, further work revealed that

this was indeed the case. McCoy, incidentally, had also been present at the meeting in which Sedgwick presented his findings but interestingly he was not a co-author of the paper. Edward Forbes initially believed that McCoy had "cooked" the fossil evidence in order to please Sedgwick (Secord 1986: 246). The Survey team were in an embarrassing position — in their detailed examination and mapping of the relevant strata they had not noticed any discontinuity in the rock sequence or in the fossil record (apart from Phillips' report of minor anomalies). They were forced back out in the field to re-examine critical sections and duly discovered previously unnoticed unconformities.

The Survey team tried to play down the significance of Sedgwick and McCoy's research and even suggested that they had only repeated work that had already been carried out by Phillips and others. But of course there is a huge difference in noticing and recording a variation or anomaly and in understanding its significance. Over the next few years Aveline, Salter and Ramsay of the Survey team, as well as Sedgwick and McCoy, carried out numerous field trips into Wales examining rock sections, clarifying the identity and range of key groups of fossils, and revising and redrawing critical boundaries on their geological maps. It does seem somewhat ironic that McCoy, who is sometimes disparaged for the quality and quantity of his fieldwork, happened to participate in fieldwork — although admittedly in the presence of Sedgwick, one of the most capable field geologists of his era — that led to the eventual resolution of one of the most intractable and historically significant disputes of the formative period of stratigraphical palaeontology.

Murchison, however, was not prepared to concede that he had been in error; by this time he had gained international acclaim for his work on the Silurian. Murchison evidently felt that the stratigraphical model that he had so assiduously and so laboriously constructed, now almost self-evident, would be in danger of being ruined, along with his scientific reputation, if he yielded to Sedgwick's revised Cambrian. Independently wealthy, Murchison was also in a powerful position institutionally, and even more so after he became Director of the Geological Survey on the death of De la Beche in 1855. In contrast to Sedgwick, his career and reputation had gone from strength to strength. He was knighted in 1846. In 1841, on his second expedition to Russia, he succeeded in making another important contribution to world geology. In the district of Perm located on the

Western flank of the Ural Mountains he identified a thick, relatively undisturbed sequence of rocks overlying the Carboniferous that he designated the 'Permian'; another significant geological system was thus identified and defined. In 1845 he published a second major work *Geology of Russia in Europe and the Ural Mountains* (co-authored with de Verneuil and von Keyserling).

Sedgwick, sadly, was never able to complete his proposed opus on the Transition strata intended as a companion volume to Conybeare and Phillips' *Outlines*. Sedgwick became increasingly embittered at Murchison's unwillingness to recant, and isolated himself from the Geological Society. This played into Murchison's hands and there were suggestions by members of the Geological Survey that Sedgwick was a zealot and probably going senile or insane.

McCoy's reputation, too, suffered by association. Edward Forbes satirically depicted Sedgwick as Don Quixote, and McCoy as Sancho Panza (Secord 1986: 267). While this representation of Sedgwick displays a certain respect for his moral integrity, it strongly suggests he is fighting for a hopeless cause and perhaps a little obsessed and a little mad. McCoy, by implication, is portrayed as a blind, loyal subordinate who would do anything to please his master. One partial consequence of the factionalism in this dispute and the defence of entrenched positions is that McCoy has never received due recognition for his contribution to resolution of the debate or for his wider contributions to palaeontology and biostratigraphy. Murchison used his influence as head of the Geological Survey, and as a member of the Geological Society and other organisations, to control the terms and direction of the debate and to prevent any changes in nomenclature or in the details of the standard geological maps of which he did not approve. For ambitious younger geologists and palaeontologists jobs were scarce and Murchison's patronage and approval were essential if they were to have any real chance of obtaining a desired position or gaining promotion. In this respect McCoy was no exception.

As the debate dragged on McCoy tried to distance himself publicly somewhat from Sedgwick although privately he remained a steadfast supporter. He tried to indicate to Murchison that he was 'just doing his job' objectively without prejudice or personal preference. In a telling letter to Murchison in June 1852, McCoy disingenuously declared his impartiality in the debate at the very time he was

urging Sedgwick to re-examine and reassess the Caradoc Sandstone sections:

"I hope that you and Professor Sedgwick have long before this settled to your mutual satisfaction the bounds of your grounds? I feared I should have come in for some knocks, although I have never intruded myself into the discussion but confined myself to identifying the fossils to the best of my ability and registering them faithfully. A smack from you would probably ruin my prospects, and I think undesirably — but I believe you spare the weak in as marked a manner as you grapple with the strong." (McCoy to Murchison, 12 June 1852, in Craig 1971: 494; Secord 1986: 271)

Murchison was aware that McCoy was an able and self-assured palaeontologist, and even a dangerous one while he was working in league with Sedgwick. Hence, it suited Murchison to give McCoy a favourable reference for the Foundation chair of Natural Science at the newly established University of Melbourne. Whether Murchison's testimonial was given because he genuinely believed that McCoy deserved the position based on merit, or simply because he wanted to get him out of the way, or both, it is difficult to say, but it did have the dual effect of removing support for and further isolating Sedgwick and removing McCoy from the mainstream activities in Great Britain. In 1854 McCoy applied for the Melbourne chair and was successful against a strong field of candidates. In early October of that year he set sail from England for Australia in the clipper *Champion of the Seas* (Wilkinson 1996: 54) and disembarked in Melbourne where he would spend most of the rest of his working life.

In the years that followed, local and international support for the Cambrian grew, but Murchison died in 1871 still opposing any change in nomenclature. The debate was effectively settled with the inclusion of the Ordovician system by Lapworth in 1879 which was inserted as a kind of no-man's land between the Cambrian and Silurian systems although, remarkably, even though the case for a new system based on the fossil evidence was compelling it took until 1960 for the Ordovician to gain full international approval (Secord 1986: 310). The new Ordovician encompassed Sedgwick's Upper Cambrian and Murchison's Lower Silurian, but one can speculate with confidence that both protagonists probably would not have been at all enamoured with Lapworth's partial appropriation of their respective geological territories.

McCoy in Melbourne

When McCoy arrived in the Colony of Victoria in December 1854 as one of the first four professors at the University of Melbourne he was still only in his early thirties and already an accomplished palaeontologist. Not only was he thoroughly familiar with Irish and British fossils but had also had some experience with Australian material. In Great Britain he had worked on Australian fossils collected by the Reverend W.B. Clarke and sent to Sedgwick at Cambridge. In 1847, he published a paper based on this work titled "On the fossil botany and zoology of the rocks associated with the coal of Australia" in the *Annals and Magazine of Natural History*. This familiarity with Australian fossils was possibly one of the factors that enticed him into immigrating to Australia. Soon after his arrival in Victoria as Professor of Natural Science, McCoy set about grappling with issues connected with the local palaeontology and stratigraphy and (with Murchison's endorsement) was appointed Palaeontologist to the Geological Survey of Victoria in 1856. He moved quickly in taking over the Colony's fledgling natural history museum and despite some spirited public opposition moved it from its city location to the grounds of the University of Melbourne (Pescott 1954; Wilkinson 1996; Rasmussen 2001). Overcoming many obstacles, including numerous bureaucratic disagreements, political disputes, and ongoing funding shortfalls, he resolutely proceeded to build the National Museum into a world-class institution. He was appointed Director in 1858.

Australian Stratigraphy Before 1850

Prior to McCoy's arrival in Australia in 1854 there had been no resident skilled palaeontologist. Geological observations had been carried out by many of the early explorers and naturalists such as Mitchell, Leichhardt, Strzelecki, Oxley, Grey, Cunningham, King, Gregory, Stokes, Sturt, Eyre, Darwin, Dana, Jukes, Clarke, Stutchbury and others. Some of these geological observations were of a high standard, e.g., those of Leichhardt (1847) and Strzelecki (1845); other observations had been more cursory and less reliable but nevertheless still interesting and suggestive. Visitors from overseas such as Darwin and Jukes made valuable observations and determinations, as did James Dana from North America who collected fossils and worked on them.



Fig. 2. Photograph of Frederick McCoy, c. 1870, seated. Johnstone, O'Shannessy & Co., photographers. H29553. La Trobe Picture Collection, State Library of Victoria.

Generally though, in order to obtain reliable fossil determinations, specimens had to be sent overseas to Britain and Europe for identification by expert palaeontologists such as Lonsdale, Morris, Owen, Sowerby, de Verneuil, de Koninck, d'Orbigny and, indeed, McCoy himself. The first steps in elucidating the stratigraphy of Australian rocks were being made but much of this work remained unconfirmed and uncertain.

Although it was well established that in a mineralogical and lithological sense rocks all over the planet were broadly comparable the old Wernerian notion of universal formations had been superseded. Grand global geological theories were now being treated with suspicion, and in keeping with prevailing scientific method most geologists adopted, or at least, subscribed to, a strict empirical and inductive approach. There were conflicting notions of what the geological evidence signified and how the stratigraphy of Australia fitted into the overall picture. In an interesting paper published in the *Tasmanian Journal of Natural Science* in 1843, the English geologist Joseph Beete Jukes, who spent from 1842 to 1846 in Australia waters as naturalist on board H.M.S. *Fly*, cautioned against drawing any hasty and premature conclusions when dealing with non-European strata:

"The European geologist, in approaching distant countries, must loose his hold of much of his previously acquired knowledge; dismiss from his mind all the arbitrary and minute divisions to which he has been hitherto accustomed, and hold them at bay until he see whether or not they be applicable to the things he is now studying. He must at once fall back on the general principles on which all geological classification ought to be founded; and, guided solely by these, separate the rocks he meets with into those portions and divisions only which naturally belong to them. When each large portion of the globe shall have been examined, and its constituent portions classified and arranged in this manner, geologists will be able to compare them one with the other, to establish well-defined bases, and make out the corresponding terms in each series, and tabulate the whole according to their united result." (Jukes 1843: 4-5)

In 1850 Jukes published a small monograph *A Sketch of the Physical Structure of Australia, so far as it is at present known* in which he summarised his conclusions concerning the geology of Australia based on his own first-hand observations combined

with information from the published reports and books of other explorers and naturalists, some of whom he met personally such as Mitchell, Strzelecki and Sturt. This memoir was the first brief but comprehensive summary of Australian stratigraphy and was a valuable synopsis of isolated geological observations from a variety of sources. Included in his book was a coloured geological map of Australia which attempted to encompass the continent as a whole, although of necessity much of the unexplored interior remained a blank. Although he discussed the Australian palaeozoic rocks in general, Jukes was reluctant to subdivide them any further based on the then current knowledge:

"... I should for the present hold that the rocks of Australia now under consideration simply as palaeozoic, and only assert that their age was included within that of our Silurian, Devonian, and Carboniferous periods." (Jukes 1850: 22)

Jukes attempted to locate Australian geology in a broader international context and tentatively noted many similarities between European and Australian geology and geomorphology but was also intrigued by the apparent differences. He was impressed by the "simplicity and uniformity of the geology when looked at on the great scale" (Jukes 1850: 79). As Vallance (1975: 22) explains, the early Australian explorers "found a continent whose physical features differed utterly from those of Europe; Instead of a great median mountain axis in Australia there were low arid plains, the mountains of Australia followed the east coast." Jukes (1850: 1) conceded that it was difficult for geologists "accustomed only to the full, varied, and complex structure of Europe" to come to terms with the very different situation in Australia. To an external observer Australian geology appeared deceptively uncomplicated. He observed that,

"Australia especially seems the very land of uniformity and monotony, the same dull and sombre vegetation, the same marsupial type of animals, spread over the whole land from the gloomy capes of the south coast of Tasmania, and the stormy Leeuwin, to the cloudless and burning skies of Torres Straits and Port Essington." (Jukes 1850: 2)

The Missing Mesozoic

Jukes, like many other observers before and after him, was impressed by the idea that Australia was a

land of anomalies. The anomalous geology and geomorphology seemingly matched the similarly anomalous flora and fauna. According to Jukes, a number of geologists had,

"been struck with the entire absence of all "secondary" formations in Australia, and with analogies between the fossil flora and fauna of our European oolitic series, and those now found living in Australia and Australian seas."

Ever since the time of Lamarck and the discovery of the bivalve *Trigonia*, found alive in Australian waters but extinct in Europe since the Mesozoic, and of various marsupials and plants which were long since extinct in Europe, there was a popular notion that Australia was 'the land that time forgot'. The rocks, the animals, the plants and even the indigenous human population were all, in comparison with Europe, very ancient. Jukes (1850: 80) noted the "total absence of any rocks of an age intermediate between the palaeozoic and tertiary, so far as is at present known or appears probable". Further on (Jukes 1850: 89) he reiterated the same point, stating: "Above the palaeozoic series there is an absolute gap, a total deficiency of all other stratified rocks, whatsoever..." except for a much more recent tertiary formation, and speculated (p. 90) that,

"We have therefore two reasons; namely, the absence of marine formations of the oolitic age, and the possible descent of some of the animals and plants from those that lived at that period; for supposing that after the deposition of palaeozoic rocks, what is now Australia was raised into dry land, and that some portion or portions of it at all events have ever since remained above the level of the sea."

This would account for the missing Mesozoic in Australia and the preservation of organic forms which long ago had become extinct in Europe.

Jukes became a highly respected geologist in Great Britain and his views carried considerable weight. On his return to England from Australia he joined the Geological Survey of Great Britain and proved himself to be a talented field geologist working in North Wales and South Staffordshire alongside other staff members such as Andrew Ramsay, William Aveline, Alfred Selwyn and palaeontologist John Salter. In 1850 he was appointed as Director of the Geological Survey of Ireland where he served with distinction until his premature death in 1869. He wrote many papers and a number of text books which presented his views to other geologists, students and the general public.

Selwyn, McCoy and the Geological Survey of Victoria

In 1852, following the discovery of gold the previous year, and two years before McCoy's arrival, the Victorian government established a Geological Survey. The Colony was extremely fortunate in gaining the services of Alfred Selwyn as Government Geologist and later Director of the Geological Survey. It would be difficult to imagine a more appropriate choice. Prior to his appointment Selwyn had considerable experience mapping the palaeozoic rocks of North Wales which were apparently a direct analogue of the gold bearing slates of Victoria. Selwyn's appointment (1852–1869) marked the commencement of systematic geological mapping in Australia. Selwyn and his staff surveyed large tracts of the Victorian countryside and after his arrival McCoy did the palaeontological determinations necessary to determine the relative ages of the strata.

It was a highly productive collaboration. Between them Selwyn and McCoy determined the line of demarcation between the Upper Silurian (now the Silurian proper) and the Lower Silurian (now the Ordovician and Cambrian) and then steadily worked their way up the geological column. Selwyn having worked at the Geological Survey of Great Britain preferred Murchison's terminology of 'Lower Silurian' for the lower strata while McCoy having been a protégé of Sedgwick preferred to use the term 'Cambrian'. Ralph Tate (1894: 490) who gave a paper titled 'Century of Geological Progress' for his presidential address for the fifth meeting of ANZAAS in Adelaide in 1893 remarked on this milestone in Australian geology, as follows:

"Up to 1853 the geology of Victoria was almost a blank. What little was then known of it was due to Mitchell, Strzelecki, and Jukes, but that little was for the most part either misread, or too indefinite to be available in the future. Thanks to the ability and zeal of Mr. Selwyn and the members of his staff, aided by the palaeontological determinations of Professor McCoy, the geological structure of Victoria was rapidly unfolded, and large tracts of country were geologically surveyed in detail..."

Further on in his address, under the subheading 'Summary of Discoveries and Original Researches', Tate continued:

"1858. Selwyn (Quart. Journ. Geol. Soc., vol. xiv, p. 533) drew the line of demarcation between the auriferous graptolite slates [Ordovi-

ean and Cambrian] and Upper Silurian [Silurian], which McCoy had shown to have faunas characteristic of the corresponding series in Europe, and thus established the fact of the specific identity of the two faunas over the whole world."

McCoy and the Global Geological Column

In 1861 McCoy published in the Victorian Exhibition Catalogue the first summary of the zoology and palaeontology of Victoria (McCoy 1861). This paper was reprinted in 1862 in the *Annals and Magazine of Natural History*. In the paper McCoy argued that based on palaeontological evidence the geological column in Australia in general conformed to that of Great Britain, Europe and North America. For the first time it was could be stated unequivocally that the rock sequences in the Southern Hemisphere, despite some provincialism, correlated well with those of the Northern Hemisphere. In other words, the geological column as deciphered in Great Britain was almost certainly a global phenomenon. This relationship held especially for the Lower Palaeozoic but McCoy believed it was generally true for the whole geological column.

McCoy declared that "... from the great quantity of fossils which I have lately examined as Palaeontologist to the Geological Survey of Victoria; and from evidence of this kind I can offer a sketch of the ancient successive changes of organic life in this country" (McCoy 1861: 160). He proceeded to discuss each of the major geological periods in turn. Beginning with the [Lower] Palaeozoic he asserted that:

The Azoic [Precambrian] rocks, I can now state, were succeeded in Victoria, exactly as in Wales, Sweden, North America, and other parts of the world in the northern hemisphere, by a series of rocks enclosing fossil remains of the well-known genera and even specific types of animal life characterizing those most ancient fossiliferous strata termed Lower Silurian by Sir R. Murchison, and Cambrian by Professor Sedgwick (McCoy 1861: 160).

McCoy then went on to discuss further correspondences between Australian biostratigraphy and Northern Hemisphere biostratigraphy for the rest of the geological column, i.e., the Upper Palaeozoic, Mesozoic, Tertiary and Recent periods. McCoy demonstrated striking global similarities in the fossil record across much of the geological column. In doing this, however, McCoy overstated the similar-

ities, particularly for the upper part of the column, and it was probably this conviction that prevented him appreciating important differences which later led to the development of the concept of Gondwana, the great southern supercontinent.

At the time of the 1861 publication McCoy had already confirmed presence of the Jurassic (or "Oolitic") based on marine fossils from Queensland in 1861 and on the flora of the Bellarine and Cape Patterson coal beds of Victoria in 1860, but evidence for the Cretaceous period had not been positively confirmed in Australia. However, in 1865 McCoy was able "... to announce for the first time with certainty the existence of the Cretaceous formations in Australia." (McCoy 1865: 333) based on fossils sent to him from Queensland that included bivalves, ammonites and ichthyosaur vertebrae. Similarly, although fossils from the Devonian period in Australia had been earlier identified by Stutchbury for example, there was some doubt about the validity of this interpretation. In an essay prepared for the 1866-67 Melbourne Intercolonial Exhibition (McCoy 1867a) and reprinted in the *Annals and Magazine of Natural History* in 1867 he claimed that he had definitely confirmed the presence of the Devonian in Australia based on marine fossils from Buchan in Gippsland. McCoy declared:

"It is with great pleasure I announce the fact of my having been able satisfactorily to determine the existence of this formation also in Australia, the limestone of Buchan in Gippsland containing characteristic corals, Placodermatous fish, and abundance of the *Spirifer laevicostata*, perfectly identical with specimens from the European Devonian Limestones of the Eifel" (McCoy 1867a: 327 (21); 1867b: 198).

For McCoy, the confirmation of these formations filled in the remaining major gaps in the geological record for Australia and demonstrated that there was an almost complete correspondence between northern hemisphere and southern hemisphere stratigraphy.

A shortened version of this paper was also made available for a North American audience and published in *The American Journal of Science and Arts* edited by Benjamin Silliman and James Dana (McCoy 1867c: 279-282). In this version, as in the original paper, when discussing the Cambrian he reiterated: "... we have in these formations the most extraordinary proof of the unexpected fact which I announced on a former occasion, that there was in the Cambrian or Lower Silurian period a nearly

complete specific uniformity of the marine faunas, not only over the whole northern hemisphere, but across the tropics, extending to this remote temperate latitude of the southern hemisphere" (McCoy 1867e: 280).

In his conclusion to the above papers McCoy reminded the reader that he had been instrumental in contributing to the solution of the Cambrian–Silurian debate and that exactly the same geological situation prevailed in Australia as it did in Great Britain. McCoy concluded:

"I can scarcely close ... without drawing attention to the curious confirmation offered in Victorian geology of the view of Professor Sedgwick and myself, that there was a real systematic line of division between the Upper Silurian and the Cambrian and Lower Silurian, at the base of the Mayhill Sandstone and over the Caradoc Sandstone — the Mayhill Sandstone, which we first defined and demonstrated to have Upper-Silurian fossils only, and the true Caradoc Sandstone full exclusively of Lower-Silurian or Cambrian types, — the previous confusion between these two sandstones, from the erroneous mingling of their fossils in collections, having given Sir Roderick Murchison the erroneous impression that his Upper and Lower Silurian groups of fossils ... could not be separated palaeontologically....The Mayhill Sandstone was one of the first formations I

recognized, on landing near Melbourne, with the usual Upper-Silurian fossils; and it is now found here, as in Wales, to be slightly unconformable to the Cambrian or Lower Silurian, forming the obvious base of the former and totally distinct [in fossils] from the latter" (McCoy 1867a: 330 (24); 1867b: 201–202; 1867e: 282).

Of course it should be acknowledged that McCoy's claims for the correlation of the Australian stratigraphy with Northern Hemisphere stratigraphy were based on not only his own work but also built on the earlier work of other geologists (e.g., see Valancey 1975; Branagan 1998). Nevertheless, it was McCoy who was the first to publish a synthesis and indicate that he was the first to fully grasp the broader implications of the local geology, palaeontology and stratigraphy and place it in a global context. Few people could have been better prepared than McCoy to appreciate the Australian stratigraphy and be able to relate it back to the British and European and American situation. He had made a significant contribution to systematically sorting, naming and describing the Palaeozoic fossils of Ireland and Britain, and had played a key role in the debate between Adam Sedgwick and Roderick Murchison on where to draw the boundary between the Cambrian and Silurian periods. At the time of his arrival in Australia he was one of the world's most experienced palaeontologists, and as Adam Sedgwick's assistant, he had played a subordinate but

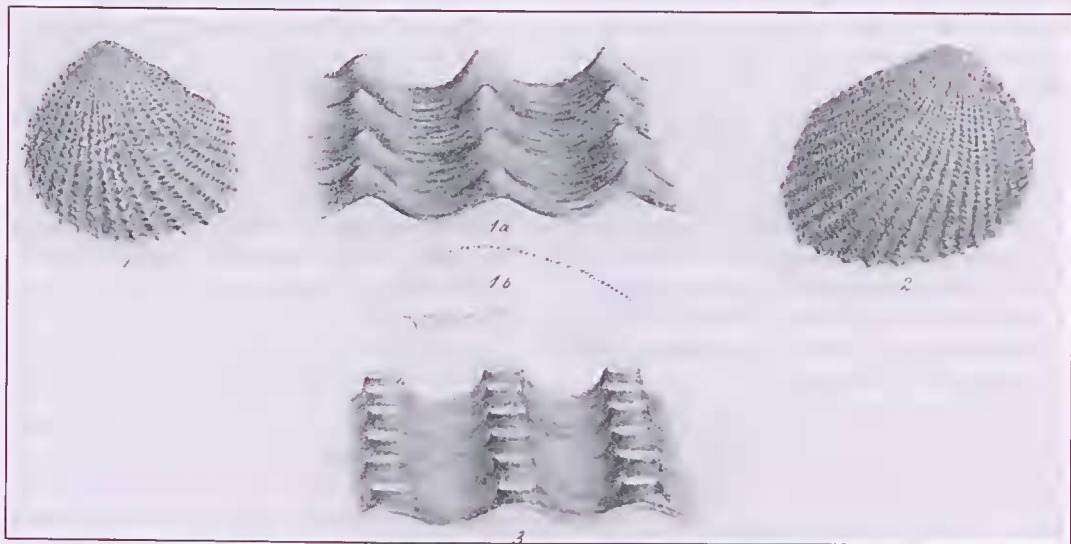


Fig. 3. Illustration of the bivalve *Trigonía acuticostata* McCoy [now *Neotrigonia acuticostata*] comparing it to the previously known *Trigonía Lamarcki* showing the acute ribs and tubercles of *T. acuticostata* in contrast to the board flattened ribs and tubercles of *T. Lamarcki*. From McCoy's *Prodromus of the Palaeontology of Victoria, Decade 2* (1875: pl. XIX).

important role in critically examining fossil evidence and relating it to the structure and lithology of a geological formation or region.

There was another factor in McCoy's readiness to fit Australian geology into a larger framework. He was attempting to defend a 'progressionist' but non-evolutionary view of the world. McCoy's geological view of the earth, like his mentor Adam Sedgwick's, was more compatible with classical Cuvierian catastrophism than with Lyellian uniformitarianism. McCoy was staunchly anti-Darwinian and rigidly believed in successive progressive "creations"; for example, in the 1862 paper when he speaks of the change from the Mesozoic to the Tertiary, he states:

"... we find that here, as in Europe, the greater part of the country sank under the sea during the Tertiary period, and every trace of the previous creations of plants and animals was destroyed and replaced by a totally different new set, both of plants and animals, more nearly related to those now occupying the land and sea of the country" (McCoy 1862: 144).

McCoy viewed these postulated successive creations in global terms.

One of the main motivations for publishing his findings on the Australian stratigraphy, as revealed by McCoy in the introduction to the 1862 paper, was to counter the argument (advanced by alleged "transmutationists" and "materialists" such as T.H. Huxley and others) that evolution occurred at highly variable rates in different regions of the globe and that Australia was, in essence, an evolutionary backwater. This was another consequence of the view that had gained credence since the time of Lamarck with the discovery of the bivalve *Trigonia* (Fig. 4) and the brachiopod *Magellania* in Australian waters and of various marsupials and plants which had become extinct in Europe. By demonstrating the universality of the geological column, and that the Southern Hemisphere, despite some provincialism, correlated geologically and biologically with the rest of the world, McCoy was attempting to demolish that argument, which, in fact, he effectively did. Unfortunately for McCoy the tide of scientific opinion was by now clearly running against progressionist ideas and his induction did little to change that. Indeed, by confirming the universality of the geological column he only helped prepare the way for a strict Lyellian uniformitarianism and thus the acceptance of gradual transmutation or evolution of organic species.

McCoy identified and described several new species of *Trigonia*. *Trigonia* was previously known

only from Mesozoic formations — and in the living state in Australian waters — but was unknown in the Tertiary. McCoy was pleased to declare that he had filled that particular gap in the fossil record. In his *Prodromus of the Palaeontology of Victoria, Decade 2* (1875: 21) he wrote,

"Being enabled to announce the discovery of three distinct species of *Trigonia* from the Pliocene and Miocene Tertiaries near Melbourne clears away this supposed exception to a general Palaeontological law, and cannot fail to be welcome, not only to geologists generally, but to the biologists engaged with the large question of the succession of life on our globe."

CONCLUSION

It is clear that Frederick McCoy made a seminal contribution towards deciphering Australian stratigraphy based on his northern hemisphere experience, and especially the key role he played in the Cambrian/Silurian debate between Adam Sedgwick and Roderick Murchison. He was the first to unambiguously and definitively demonstrate that the Australian geology and stratigraphy correlated fundamentally with that of the northern hemisphere contrary to the standard European view of the time. Debate has continued until the present day on just how complete the correlations actually are. It appears that McCoy's achievements were largely underrated by the British establishment in his day, and his critical contribution has gone almost entirely unnoticed and unacknowledged by modern historians. McCoy certainly received criticism on aspects of his work by some of his contemporaries and became embroiled in a number of controversies both locally in Australia and overseas in England and Ireland. Some of this condemnation has undoubtedly contributed towards a lack of appreciation of his more positive contributions.

Perhaps another reason McCoy's achievement is not more appreciated today is because the global geological column is now taken for granted. The realization that the Southern Hemisphere was, in general terms, geologically compatible with Europe and North America was an important confirmation of the universality of geological phenomena. McCoy's anti-evolutionary stance, which he shared with many of his contemporaries including Sedgwick and Murchison, is a further reason that his scientific achievements have not been widely

appreciated. As Rupke (1983) notes many of these pre-Darwinian and anti-Darwinian scientific contributors have been either harshly dealt with by historians, or dismissed and ignored.

Because of his extensive commitments as Director of the National Museum, Professor of Natural Science at the University of Melbourne, and numerous other duties such as descriptive zoological work, McCoy never approached the prodigious output that he achieved in Great Britain in his Australian palaeontological work. Funding difficulties, bureaucratic arguments and political complications also contributed to delays in publication. Work on his *Prodromus of the Palaeontology of Victoria*, published serially between 1874 and 1882, was actually started in 1858 — the series remained unfinished with the seventh issue or 'decade'. His *Prodromus of the Zoology of Victoria* was published in twenty decades between 1878 and 1890.

The breadth of McCoy's contributions to palaeontology and modern zoology, his scientific, philosophical and theological activities aimed at the public, and his administration of public institutions and societies, have made McCoy a difficult individual to grapple with. This difficulty should not blind us to the fact that in his day he was an eminent authority and made lasting contributions not only locally but to world science generally. He was one of the pioneering figures of international palaeontology and biostratigraphy and until the arrival on the local scene of Ralph Tate and Robert Etheridge, Jr. (Vallance 1978: 247) he was Australia's leading palaeontologist and arguably in his mature years "the acknowledged chief of the scientific world of Australasia" (Anon. 1899: 283).

REFERENCES

- ANON., 1899. Obituary. Professor Sir Frederick McCoy, K.C.M.G., M.A., D.Sc. (CANTAB), F.R.S., F.G.S. *Geological Magazine, New Series, Decade 4*, 6: 283–287.
- ARCHBOLD, N. W., 2001. Frederick McCoy and the Phylum Brachiopoda. *The Victorian Naturalist* 118(5): 178–185.
- BASSETT, D. A., 1991. Roderick Murchison's The Silurian System: A Sesquicentennial Tribute. In *The Murchison Symposium: proceedings of an international conference on The Silurian System*, M. G. Bassett, P. D. Lane & D. Edwards eds, The Palaeontological Association, London. *Special Papers in Palaeontology* 44: 7–90.
- BERRY, W. B. N., 1968. *Growth of a Prehistoric Time Scale Based on Organic Evolution*. W. H. Freeman, San Francisco and London.
- BRANAGAN, D. F., 1998. Geological Periodization. In *Sciences of the Earth. An Encyclopedia of Events, People, and Phenomena*, G. A. Good, ed., Garland Publishing, Inc., New York and London, Vol. 1: 306–314.
- CONYBEARE, W. D. & PHILLIPS, W., 1822. *Outlines of the Geology of England and Wales, with an Introductory Compendium of the General Principles of that Science, and Comparative Views of the Structure of Foreign Countries*. William Phillips, London.
- CRAIG, G. Y., 1971. Letters Concerning the Cambrian-Silurian Controversy of 1852. *Journal of the Geological Society of London* 127: 483–500.
- DARRAGH, T. A., 1992. Frederick McCoy. *The Fossil Collector Bulletin* 36: 15–22.
- DARRAGH, T. A., 2001. Frederick McCoy: the Irish Years. *The Victorian Naturalist* 118(5): 160–164.
- FENDLEY, G. C., 1969. Sir Frederick McCoy (1817–1899). *Australian Dictionary of Biography* 1851–1890, 5: 134–136.
- GOHAU, G., 1990. *A History of Geology*. Rutgers University Press, New Brunswick and London.
- GRADSTEIN, F. M., OGG, J. G. et al., 2004. *A Geologic Time Scale 2004*. Cambridge University Press, Cambridge.
- GRIFFITH, R., 1841. *An address delivered at the ninth annual meeting of the Geological Society of Dublin, on the 12th of February 1840*. Hodges & Smith, Dublin.
- HECKER, R. TIL., 1887. Na Siluriiskom Plato. *Geologicheskikh Ocherki pa Istorii Znanii Vyp.* 24: 1–153.
- HERRIES DAVIES, G. L., 1983. *Sheets of many colours. The mapping of Ireland's rocks 1750–1890*. Royal Dublin Society, Dublin.
- HERRIES DAVIES, G. L., 1995. *North from the Hook. 150 years of the Geological Survey of Ireland*. Geological Survey of Ireland, Dublin.
- HUDSON, J., 1843. *A complete guide to the Lakes ... with Mr Wordsworth's description of the scenery of the country, etc. and three letters on the geology of the Lake District by Professor Sedgwick*. Kendal.

- INTERNATIONAL COMMISSION ON STRATIGRAPHY, 2004. *International Stratigraphic Chart*. International Commission on Stratigraphy, International Union of Geological Sciences.
- IVANOVSKIĬ, A. B., 1973. Istoriye Izucheniya Paleozoiskikh Korallov i Stomatoporoidei. Moskva, Izdatel'stvo 'Nauka'. *Akademiya Nauk SSSR, Sibirskoe Otdeleniye, Trudy Instituta Geologii i Geofiziki. Vypusk 131*: 1–288.
- JUKES, J. B., 1846 (published 1843). A few remarks on the nomenclature and classification of rock formations in new countries. *The Tasmanian Journal of Natural Science* 2(6): 1–12.
- JUKES, J. B., 1850. *A sketch of the physical structure of Australia, so far as it is at present known*. T. & W. Boone, London.
- KONINCK, L. DE., 1842–1844. *Description des Animaux Fossiles qui se trouvent dans le Terrain Carbonifere de Belgique*. H. Dessain, Liege.
- LAPWORTH, C., 1879. On the Tripartite Classification of the Lower Palaeozoic Rocks. *Geological Magazine, New Series, Decade 2* 6: 1–15.
- LEICHHARDT, L., 1847. *Journal of an Overland Expedition in Australia, from Moreton Bay to Port Essington, a distance of upwards of 3000 miles, during the years 1844–1845*. T. and W. Boone, London.
- MCCOY, F., 1838. Remarks on Mr. Eyton's Arrangement of the Gulls. *Magazine of Natural History, New Series* 2: 487–490.
- MCCOY, F., 1839. On a new genus of Entomostraca from the Mountain Limestone. *Journal of the Geological Society of Dublin* 2: 91–94.
- MCCOY, F., 1844. *A Synopsis of the Characters of the Carboniferous Limestone Fossils of Ireland*. Dublin University Press, Dublin.
- MCCOY, F., 1846. *A Synopsis of the Silurian Fossils of Ireland*. Dublin University Press, Dublin.
- MCCOY, F., 1847. On the fossil botany and zoology of the rocks associated with the coal of Australia. *Annals and Magazine of Natural History* 20: 145–157, 226–236, 298–312.
- MCCOY, F., 1851. *Description of the British Palaeozoic fossils in the Geological Museum of the University of Cambridge. Fasciculus 1*. University of Cambridge Press, Cambridge.
- MCCOY, F., 1852. *Description of the British Palaeozoic fossils in the Geological Museum of the University of Cambridge. Fasciculus 2*. University of Cambridge Press, Cambridge.
- MCCOY, F., 1854. *Contributions to British Palaeontology, or first descriptions of three hundred and sixty species and several genera of fossil Radiata, Articulata, Mollusca, and Pisces from the Tertiary, Cretaceous, Oolitic, and Palaeozoic strata of Great Britain*. MacMillan and Co., Cambridge.
- MCCOY, F., 1855. *Description of the British Palaeozoic fossils in the Geological Museum of the University of Cambridge. Fasciculus 3*. University of Cambridge Press, Cambridge.
- MCCOY, F., 1861. On the Ancient and Recent Natural History of Victoria. *Catalogue of the Victorian Exhibition, 1861: With Prefatory Essays, indicating the Progress, Resources, and Physical Characteristics of the Colony*. John Ferres, Government Printer, Melbourne, 159–174.
- MCCOY, F., 1862. Note on the Ancient and Recent Natural History of Victoria. *Annals and Magazine of Natural History, Series 3*, 9: 137–150.
- MCCOY, F., 1865. Note on the Cretaceous deposits of Australia. *Annals and Magazine of Natural History, Series 3*, 16: 333–334.
- MCCOY, F., 1867a. On the recent zoology and palaeontology of Victoria. *Intercolonial Exhibition of Australasia, 1866–1867, Official Record, containing introduction, catalogues, reports and awards of the Jurors, and essays and statistics on the social and economic resources of the Australian Colonies*. Blundell & Co., Melbourne, 309–330 (1–24).
- MCCOY, F., 1867b. On the recent zoology and palaeontology of Victoria. *Annals and Magazine of Natural History, Series 3*, 20: 175–202.
- MCCOY, F., 1867c. On the Palaeontology of Victoria, South (sic) Australia. *American Journal of Science and Arts* 44: 279–282.
- MCCOY, F., 1874–1882. *Prodromus of the Palaeontology of Victoria; or, figures and descriptions of Victorian Organic Remains*. John Ferres, Government Printer, Melbourne.
- MCCOY, F., 1878–1890. *Prodromus of the Zoology of Victoria*, George Robertson, Melbourne and Trübner & Co., London.
- MCCOY, F., 1891. Minutes of evidence. Royal Commission on Coal. Final Report of the Royal Commission appointed to inquire as to the

- best means of Developing and Promoting the Coal Industry in Victoria. *Victoria, Votes and Proceedings of the Legislative Assembly for the session 1891*, 6: 43–52.
- MURCHISON, R. I., 1839. *The Silurian System, Founded on Geological Researches in the Counties of Salop, Hereford, Radnor, Montgomery, Caernarthen, Brecon, Pembroke, Monmouth, Gloucester, Worcester, and Stafford; With Descriptions of the Coal-fields and Overlying Formations*. John Murray, London.
- MURCHISON, R. I., 1852. On the Meaning of the Term "Silurian System" as Adopted by Geologists in Various Countries During the Last Ten Years. *Quarterly Journal of the Geological Society of London* 8: 173–184.
- MURCHISON, R. I., VERNEUIL, E. DE, et al., 1845. *The Geology of Russia in Europe and the Ural Mountains. Vol. 1*. John Murray, London.
- PESCOTT, R. T. M., 1954. *Collections of a Century. The History of the First Hundred Years of the National Museum of Victoria*. National Museum of Victoria, Melbourne.
- PHILLIPS, J., 1836. *Illustrations of the Geology of Yorkshire; or a description of the strata and organic remains: accompanied by a geological map, sections, and diagrams, and figures of the fossils. Part II. The Mountain Limestone District*. John Murray, London.
- PHILLIPS, J., 1841. *Figures and descriptions of the Palaeozoic fossils of Cornwall, Devon and West Somerset; observed in the course of the Ordinance Geological Survey of that district*. Longman, Brown, Green & Longmans, London.
- PHILLIPS, J., 1848. The Malvern Hills Compared with the Palaeozoic Districts of Abberley, &c. *Memoirs of the Geological Survey of Great Britain* 2: 1–386.
- PORTER, R., 1977. *The making of geology. Earth science in Britain 1660–1815*. Cambridge University Press, Cambridge.
- RASMUSSEN, C., 2001. *A museum for the people. A history of Museum Victoria and its predecessors, 1854–2000*. Scribe Publications, Melbourne.
- RUDWICK, M. J. S., 1975. Adam Sedgwick. *Dictionary of Scientific Biography*. C. H. Gillispie (editor-in-chief). Charles Scribner's Sons, New York, 12: 275–279.
- RUDWICK, M. J. S., 1985. *The Great Devonian Controversy. The Shaping of Scientific Knowledge Among Gentlemanly Specialists*. University of Chicago Press, Chicago and London.
- RUPKE, N. A., 1983. *The Great Chain of History. William Buckland and the English School of Geology (1814–1849)*. Clarendon Press, Oxford.
- SECORD, J. A., 1986. *Controversy in Victorian geology. The Cambrian-Silurian dispute*. Princeton University Press, Princeton, New Jersey.
- SEDGWICK, A., 1831a. Address. On announcing the first award of the Wollaston Prize. *Proceedings of the Geological Society of London* 1: 270–279.
- SEDGWICK, A., 1831b. Address to the Geological Society, Delivered on the Evening of the 18th February 1831. *Proceedings of the Geological Society of London* 1: 281–316.
- SEDGWICK, A., 1852. Sedgwick to Lord Lieutenant of Ireland, 13 December 1852, McCoy papers, Mitchell Library, State Library of New South Wales, CY reel 499: 294–7.
- SEDGWICK, A. & MCCOY, F., 1855. A Synopsis of the Classification of the British Palaeozoic Rocks. *A Synopsis of the Classification of the British Palaeozoic Rocks, by the Rev. Adam Sedgwick, M.A. F.R.S., with a Systematic Description of the British Palaeozoic Fossils in the Geological Museum of the University of Cambridge, by Frederick McCoy. F.G.S. Hon. F.C.P.S.*, John W. Parker and Son, London; Deighton, Bell & Co. and Macmillan & Co., Cambridge.
- SEDGWICK, A. & MURCHISON, R. I., 1836. On the Silurian and Cambrian Systems, Exhibiting the Order in Which the Older Sedimentary Strata Succeed Each Other in England and Wales. *British Association for the Advancement of Science, 1835 Report, Part 2*: 59–61.
- SPEAKMAN, C., 1982. *Adam Sedgwick, Geologist and Dalesman, 1785–1873. A Biography in Twelve Themes*. Heathfield, East Sussex, Published jointly by The Broad Oak Press Limited, The Geological Society of London and Trinity College, Cambridge.
- STAFFORD, R. A., 1989. *Scientist of Empire. Sir Roddick Murchison, Scientific Exploration and Victorian Imperialism*. Cambridge University Press, Cambridge.

- STRZELECKI, P. E., 1845. *Physical description of New South Wales and Van Diemen's Land*. Longman, Brown, Green, London.
- TATE, R., 1894. Inaugural address. *Report of the Fifth meeting of the Australian Association for the Advancement of Science held at Adelaide, South Australia, September 1893*. R. Tate, E. H. Rennie & W. H. Bragg, eds, Australian Association for the Advancement of Science, Adelaide, 1-69.
- THACKRAY, J. C., 1978. R. I. Murchison's *Silurian System* (1839). *Journal of the Society for the Bibliography of Natural History* 9(1): 61-73.
- VALLANCE, T. G., 1975. Origins of Australian geology. *Proceedings of the Linnean Society of New South Wales* 100(1): 13-43.
- VALLANCE, T. G., 1978. Pioneers and leaders — a record of Australian palaeontology. *Alcheringa* 2: 243-250.
- WILKINSON, I., 1996. The Battle for the Museum. Frederick McCoy and the Establishment of the National Museum of Victoria at the University of Melbourne. *Historical Records of Australian Science* 11: 1-11.
- WOODWARD, H. B., 1907. *The history of the Geological Society of London*. Geological Society of London, London.
- WYSE JACKSON, P. N. & MONAGHAN, N. T., 1994. Frederick McCoy. An eminent Victorian palaeontologist and his synopsis of Irish Palaeontology of 1844 and 1846. *Geology Today* 10: 231-234.
- ZITTEL, K. A. VON, 1901 (Reprinted 1962). *History of Geology & Palaeontology to the End of the Nineteenth Century*. Walter Scott, London.

SEQUENCE AND EVENT STRATIGRAPHY OF SILURIAN STRATA OF THE CINCINNATI ARCH REGION: CORRELATIONS WITH NEW YORK-ONTARIO SUCCESSIONS

CARLTON E. BRETT & DAVID C. RAY¹

Department of Geology, University of Cincinnati, Cincinnati, Ohio 45221-0013

¹ Present address: School of Geography, Earth, and Environmental Sciences,
The University of Birmingham, Edgbaston, Birmingham B15 2TT, UK

BRETT, C. E. & RAY, D. C., 2005. Sequence and event stratigraphy of Silurian strata of the Cincinnati Arch Region: correlations with New York-Ontario successions. *Proceedings of the Royal Society of Victoria* 117(2): 175–198. ISSN 0035-9211.

The Lower Silurian (Llandovery–Wenlock) of the eastern Cincinnati Arch in south central Ohio and northern Kentucky, USA, has been restudied from the standpoint of sequence and event stratigraphy. Despite a multiplicity of local stratigraphic terms a relatively simple pattern emerges. The succession, which comprises a major portion of the Tutelo Supersequence, is bounded at the base by the Cherokee Unconformity. It is further divisible into a series of six third order composite sequences and component fourth order subsequences that are correlative with Silurian sequences S-I, S-II and S-IV to S-VII, previously recognized in the Appalachian Basin. As in western New York-Ontario, sequence S-III has been removed by erosion at a major regionally angular late Llandovery unconformity. Correlation is corroborated by biostratigraphy and distinct event beds, including a very widespread deformed horizon (probable seismite), faunal epiboles, reef horizons, and probable K-bentonites. Similar patterns in the Silurian of the Niagara Escarpment in southern Ontario and western New York indicate probable alloecyclic (eustatic) control over sequence development. However, the relatively simple sequence patterns are locally modified by epeirogenic uplift and subsidence. In particular, major truncation below sequence S-IV and thinning of strata in higher sequences to the west in Ontario and in western Ohio indicate that the Findlay-Algonquin Arch system was a positive area (forebulge?) by later Llandovery time. Moreover, a second area of regional uplift developed to the southwest in the vicinity of north central Kentucky during Wenlock time, as indicated by thinning and erosional truncation of parts of sequences S-V and S-VI. Changing loci of local uplift, as well as widespread K-bentonites and a major seismite are indicative of renewed tectonism of the Salinic Orogeny during this time.

Keywords: Silurian, Cincinnati Arch, sequence stratigraphy, eustasy, tectonics

IN recent years outcrop-based stratigraphic studies in cratonic areas have undergone a paradigmatic shift from a primarily descriptive approach to a focus on understanding the architecture of sedimentary accumulations within a sequence stratigraphic context (Wilgus et al. 1988; Kidwell 1991; Holland 1993, 1998; Dennison & Ettensohn 1994; Brett 1995, 1998; Emery & Myers 1996; Witzke et al. 1996; Catuncaanu 2002; Coe & Church 2004). This avenue of research has developed indirectly from seismic profiling of continental margin sediments and from the recognition of large, unconformity-bounded depositional wedges (“sequences”) in these profiles. Originally, sequences were defined very broadly as large intervals of strata bounded by very major unconformities (“first-” or “second-order” cycles recording tens of millions of years; see Vail et al. 1977, 1991), such as the six classic “super sequences” of Sloss (1963). Seismic stratigraphers were able to

refine correlations and demonstrate that these large-scale unconformity-bounded packages are subdivisible into smaller intervals representing approximately 0.5 to 3 million years, typically termed “third-order” sequences. Sequence stratigraphers also recognized distinctive phases of sequences (“systems tracts”) as the product of sea-level oscillations translated in a biased way into the sedimentary record (Vail et al. 1977, 1991; Haq et al. 1987; Van Wagoner et al. 1988; Emery & Myers 1996). Subsequently, seismic stratigraphers working in the field recognized that third-order packages could frequently be subdivided into smaller scale, “fourth-”, “fifth-”, and even “sixth-” and higher order cycles.

The purpose of this contribution is to examine and discuss Silurian strata of the eastern Cincinnati Arch region in eastern North America (Figs. 1, 2) in the context of sequence stratigraphy. Research on the sequence stratigraphy of Silurian rocks in the

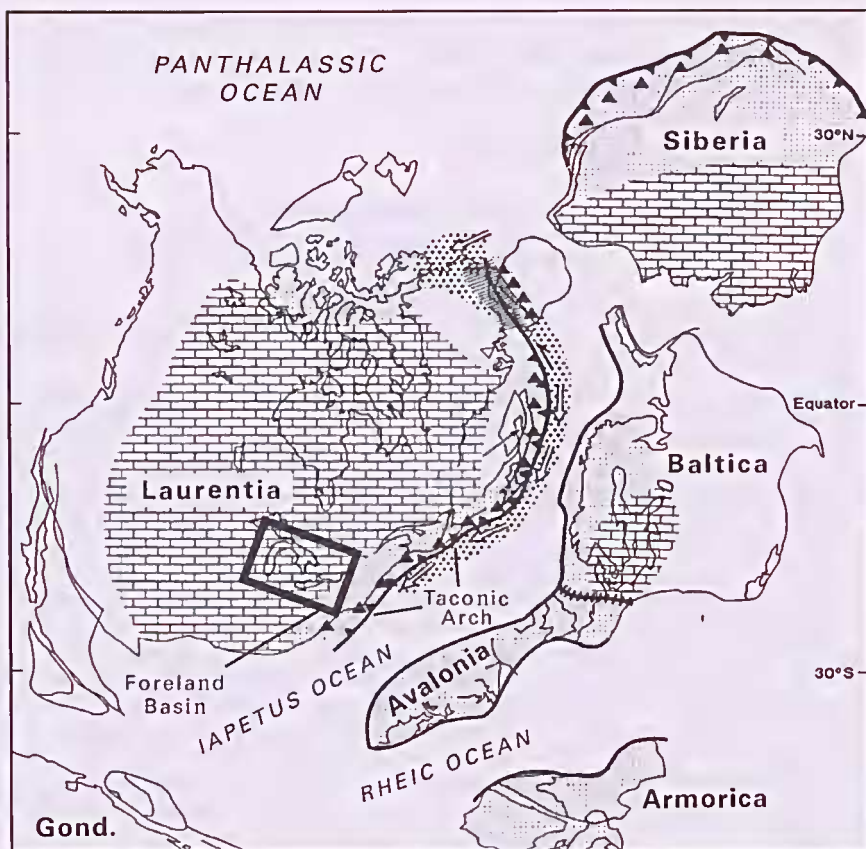


Fig 1. Palaeogeographic reconstruction of Laurentia (ancestral North America) and adjacent palaeocontinents during Early Silurian time. Note position of study area, shown with box and of the Taconic Arch and peripheral foreland basin. Gond.: Gondwana. Modified from Scotese (1990).

northern Appalachian Basin (Brett et al. 1990, 1994, 1998) has resulted in recognition of about eight widespread, unconformity-bounded packages that may be assigned "third-order" status, as well as a large number of smaller ("fourth-order") sequences. Recently, sequence analysis of correlative units in Ohio and Kentucky, USA, has led to recognition of about six, probably correlative "third-order" sequences in the Cincinnati Arch region (Fig. 2). Interregional correlation of these sequences is facilitated by the conodont biostratigraphic studies of Kleffner (1989) as well as the detailed subsurface study of Lukasik (1988).

We believe that the application of sequence analysis to this classic stratigraphic succession is providing critical new insights into the depositional dynamics and history of this region. In turn, these well-exposed strata may potentially help to refine models and approaches to stratigraphy that will aid in interpretation of other areas.

GEOLOGIC SETTING

Sediments of Early Silurian (Llandovery-Wenlock) age in southern Ohio and northern Kentucky accumulated in a shallow-marine subtropical setting about 20–25° south of the palaeoequator (Scotese 1990; Ettensohn 1992a,b; Figs. 1, 2). This setting was well situated to be affected by subtropical hurricanes and there is abundant evidence for storm deposition (tempestites) in the Silurian.

During the Late Ordovician, eastern Laurentia underwent collisions with island arc to microcontinental terranes, first (during the early Turinian or mid Caradoc Age) in the southern Appalachian region where collision produced the Blountian highlands and later (during the late Shermanian; late Caradoc) in the area of the New York Promontory where the Hamburg Klippe (SE Pennsylvania) and Taconic allochthons were emplaced as accretionary wedges onto the

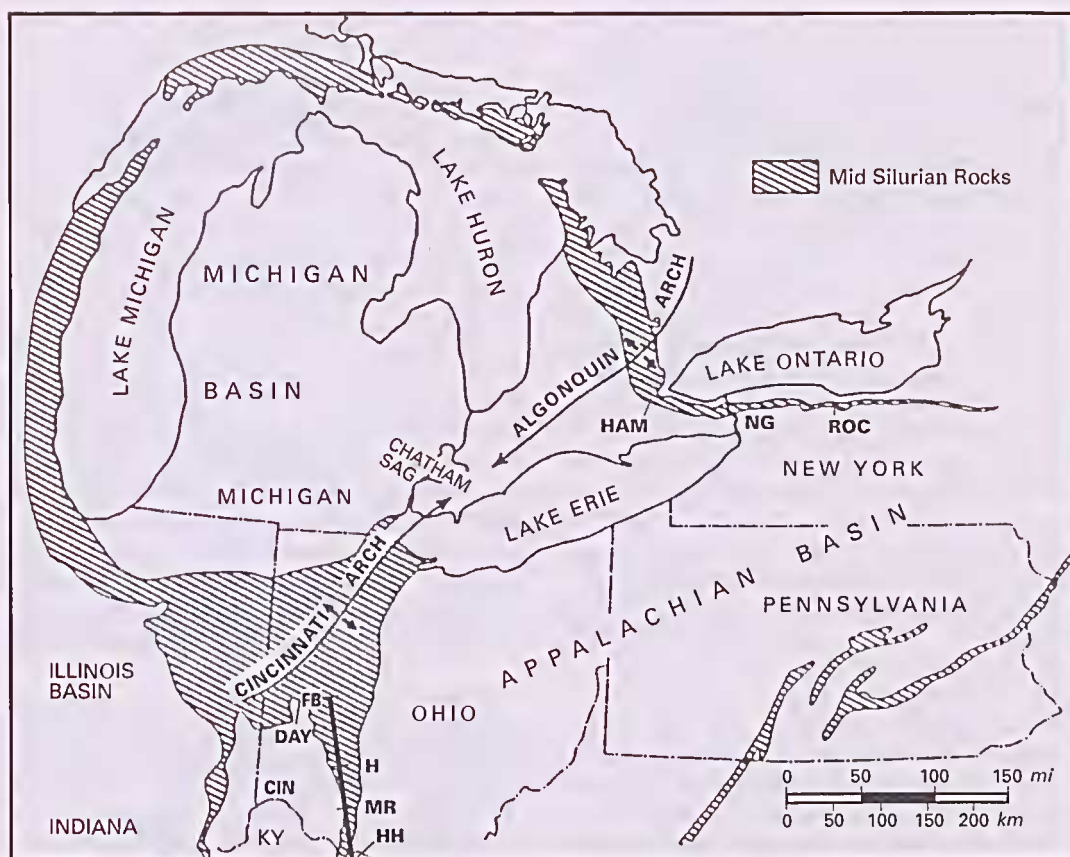


Fig 2. Map showing geomorphic features of eastern North America and outcrop belt of the Silurian; bar shows position of cross sections in Figures 6 (in part) and 14; abbreviations: DAY: Dayton, Ohio; CIN.: Cincinnati, Ohio; FB: Fairborn Quarry near Dayton, Ohio; HAM: Hamilton, ONT; H: roadcut on Rte. 62 at Hillsboro, Ohio; HH: Cut on AA Highway at Herron Hill, Kentucky; MR: cut on US Rte. 32 at Measley Ridge, near Peebles, Ohio; NG: Niagara Gorge, NY, ONT; ROC: Rochester, NY. Base map modified from Telford (1978).

Laurentian margin forming the Taconian highlands (Ettensohn 1992c; Ettensohn & Pashin 1992; Fig. 1). Most of the siliciclastic muds and silts of the Upper Ordovician (Cineinnatian) and Lower Silurian were probably derived from these upland areas to the east and southeast. A relatively small gap existed between the two upland regions that might have served to funnel storms into the present-day Tristate region (Ohio-Kentucky-Indiana; Ettensohn 1992b, 2004).

The Taconic foreland basin (Fig. 1), a relatively narrow trough produced by thrust loading, extended southward from Quebec to Alabama (Beaumont et al. 1988; Ettensohn 1991; Ettensohn & Brett 2002). This area of active subsidence accumulated a thick wedge (up to 3900 m) of siliciclastic sands, silts and muds during the Late Ordovician- Early Silurian (Ettensohn 2004).

During the latest Ordovician to early Silurian, a major sea-level lowstand, probably related to continental glaciation in Gondwana (Brenchley et al. 1994; Brenchley 2004), caused the widespread withdrawal of seas from the Cineinnatian area and created a major erosion surface, the Cherokee Unconformity (Figs. 3, 4). Evidence for local Llandovery glacial and interglacial events in South America (Grahn & Caputo 1992) suggests glaciostatic control at least on Early Silurian cycles. Transgression in the Early Silurian (Rhuddanian) enabled deposition of marine siliciclastics and carbonates over the unconformity. This transgression spread an elastic wedge over much of the Appalachian Basin but elastic influx appears to have had rather little influence in the study area in which Brassfield carbonates were deposited contemporaneously (Gordon & Ettensohn 1984).

The Early Silurian interval is typically considered to have been tectonically quiescent. However, recent study (Ettensohn & Brett 2002; Ettensohn 2004; Fig. 3) indicates that a late tectophase of the Taconic Orogeny may have taken place at this time. Furthermore, a cluster of Early Silurian K-bentonites in the southern Appalachians indicates ongoing volcanism during this time (Huff et al. 1997). There is also some evidence for renewed tectonism, which produced renewed subsidence and a pulse of siliciclastics into the Appalachian basin during medial Silurian (latest Llandovery) time (Ettensohn 2004). In addition, recently discovered K-bentonites provide evidence for increased volcanism during late Llandovery-mid Wenlock time (Huff et al. 1997; Ray & Brett 2001; Brett & Ray 2001). Locally, evidence for renewed tectonism is provided not only by thick shales and siltstones of the Crab Orchard-Estill formations, but also by development of regional angular unconformities (Lukasik 1988; Goodman & Brett 1994; Ettensohn & Brett 1998; Figs. 3, 4). Regional truncation of Lower Silurian units in central Ohio and northward into the Hamilton, Ontario, area suggests that the Findlay-Algonquin Arch, the northeastern branch of the Cincinnati Arch, was uplifted during late Llandovery time (Ettensohn & Pashin 1992). The affected area cuts obliquely across the position of the former Sebrec Trough. This could be viewed as evidence of reactivation of older deep-seated structures related to basement faults, but it has also been interpreted as development of a forebulge related to thrust loading and subsidence in the adjacent Appalachian foreland basin. In a sense, this could be viewed as the origin of the Cincinnati Arch (Ettensohn & Pashin 1992), although, in fact, the area of uplift was offset from the center of the present structural arch. The new stratigraphic correlations presented here will ultimately be used to refine understanding of migrating arches (forebulges) and depocenters through the Silurian.

GENERAL STRATIGRAPHY OF SILURIAN STRATA OF THE EASTERN CINCINNATI ARCH

Study Area and Methods

Recently, a series of detailed stratigraphic sections have been measured and correlated in southern Ohio into northern Kentucky along an approximately northwest-southeast line totaling about 170 km from

the northern to the western flank of the present Cincinnati Arch, a broad, gentle antiformal feature that occupies portions of Ohio, Indiana, and Kentucky (Figs. 2, 4; Ettensohn & Pashin 1992). Measured sections span from Ludlow Corners, northwest of Dayton, Ohio southeastward through Highland and Adams counties, and across the Ohio River to cuts along the AA Highway near Vanceburg, Kentucky. Although this cross section takes in areas of disparate stratigraphic nomenclature, correlation of units appears relatively straightforward, at least when regional truncation of beds at unconformities is taken into account. Previous correlations were complicated by misidentification of the Estill (Crab Orchard) Shale with the somewhat younger, and lithologically distinctive Rochester Shale of New York and Ontario (cf. Potter et al. 1991). Also, the Laurel Formation of Indiana was incorrectly correlated with a thin carbonate beneath the Massie Shale in the Dayton area rather than with the Euphemia-lower Lilly formations (see Figures 12, 14, herein). Finally, while previous workers recognized an important unconformity

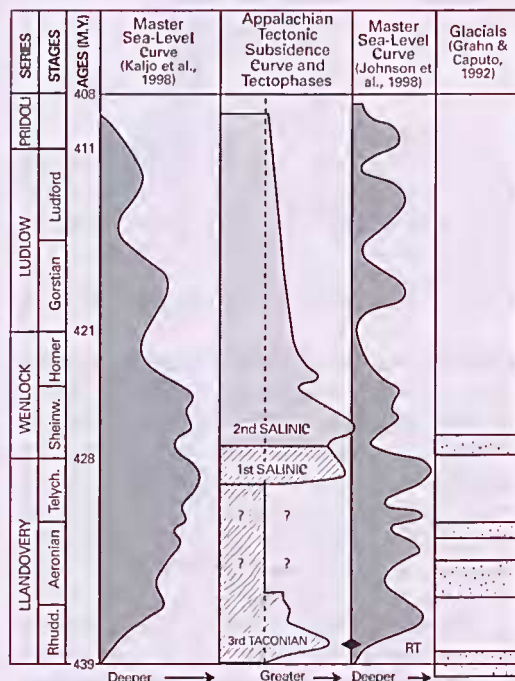


Fig. 3. Silurian eustatic and tectonic events; note two slightly differing sea-level curves; tectophases include an early Llandovery pulse of the Taconic Orogeny and at least two tectophases of the Silurian Salinic Orogeny; also shown are documented ages of glacial deposits in South America. Modified from Ettensohn and Brett (1998).

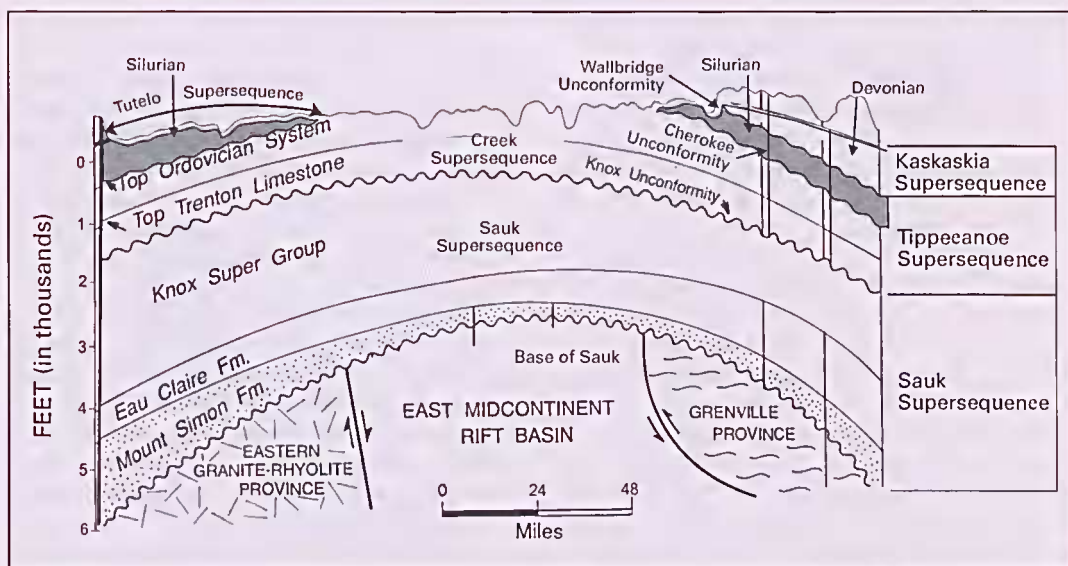


Fig. 4. Schematic cross section of the Cincinnati arch region of southern Ohio/northern Kentucky, showing unconformities (supersequence boundaries) and Sloss sequences in the Ordovician. Note truncation of Silurian in center of arch. Adapted from Potter (1996).

beneath the Dayton Formation (Foerste 1906, 1935; Lukasik 1988), they failed to identify key sequence bounding truncation surfaces within the Bisher Formation and at the base of the Lilly Dolostone. Once these truncation surfaces were recognized the regional stratigraphic pattern was clarified and new patterns of paleogeography became evident.

Initially, we suspected that the Dayton-Vanceburg cross section would provide details of expansion of strata from the Algonquin Arch into the Appalachian foreland. However, it became clear that, while some Lower Silurian units (e.g., Estill Shale) showed a general southeastward expansion in thickness, upper units displayed a more complex pattern. In particular, the Massie (=Rochester) Shale thins both to the northwest and to the southeast of a maximum in Highland Co., Ohio. These observations suggest that the Findlay-Algonquin Arch was active during the middle to late Llandovery. A secondary arch developed later during the medial Silurian, in the vicinity of the later Waverly Arch in northern Kentucky.

Supersequences

At the largest scale, the rocks of the Cincinnati Arch-Appalachian Basin region are subdivisible into great unconformity-bounded packages of the scale recognized long ago by Sloss (1963). These large-

scale "supersequences" are bounded by major unconformities that are traceable widely over the North American craton and perhaps globally (Dennison & Ettensohn 1994; Figs. 3, 4).

At their top, the Upper Ordovician rocks are bounded by a second great unconformity, the Cherokee Unconformity (Dennison & Head 1975). This unconformity is of global extent but of shorter duration (3–4 million years) than the Knox Unconformity, at the base of the Middle Ordovician Creek Supersequence, having removed only the uppermost Ordovician Gamaehian Stage over most of North America (Fig. 4). The Cherokee Unconformity is typically attributed to a major lowstand or drop in global sea level, probably of glacio-eustatic origin and related to coeval continental glaciation in North Africa (Brenchley et al. 1994; Brenchley 2004). This unconformity is typically nearly planar in outcrop but may display minor relief. In southern Ohio and northern Kentucky, the unconformity is in places very sharply delineated at the top of Upper Ordovician shales of the Drakes Formation, a greenish to red mottled mudstone with abundant thin siltstone layers that appears to represent the distal feather edge of the Queenston clastic wedge (Fig. 5). These variegated mudstones are sharply overlain by the Early Silurian (Rhuddanian) Brassfield Dolostone (Gordon & Ettensohn 1984). Although the Cherokee Unconformity is typically nearly flat and featureless, it

clearly truncates different units in various localities and is a regionally angular beveled surface.

The Silurian strata are typically assigned to the Tutelo Supersequence (formerly combined with Creek as the Tippecanoe Megasequence of Sloss 1963; Fig. 4). The top of the Silurian in eastern Kentucky and southern Ohio is defined by a second major "second-order" sequence boundary comprising actually a combination of two or more unconformities. The lower, or Wallbridge Unconformity, separates upper Lower to Middle Devonian (Emasian-Eifelian) deposits of the Kaskaskia Supersequence (Sloss 1963; Dennison & Head 1975) from Upper Silurian to Lower Devonian deposits. In most areas of the Midcontinent, a higher Taghanic unconformity that occurred during a late Middle Devonian sea-level drawdown oversteps the Wallbridge Unconformity, and Middle Devonian deposits are absent. Both unconformities appear to record a combination of tectonic and eustatic signatures in their formation (Ettensohn 2004).

SEQUENCE STRATIGRAPHY OF SILURIAN STRATA OF CINCINNATI ARCH REGION

Cratonic Third Order Sequence Stratigraphy: General Concepts

Decimeter-scale unconformity-bounded depositional sequences are present within the Silurian strata

of the Cincinnati Arch region (Fig. 6). These are comparable in duration (1 to 5 million years) to the "third-order" sequences recognized by seismic stratigraphers (see for example Vail et al. 1991). In particular, they are subdivisible into smaller-scale sequences, parasequences, and systems tracts. Before discussing these stratigraphic packages in detail, the basic concepts of sequence stratigraphy will be reviewed briefly (see Catuneanu 2002; Coc & Church 2003 and, for recent summaries).

Sequences are relatively conformable packages of strata bounded by unconformities formed during sea-level lowstands. It has been recognized for some time that larger scale sequences typically are overgeneralized and that most such sequences are in fact composite sequences (Myers & Milton 1996). Such composite sequences can be subdivided into smaller scale cyclic intervals. Some of these are unconformity-bounded units that exhibit a pattern of relative deepening followed by shallowing (sub-sequences of Brett et al. 1990), whereas others are distinctly asymmetrical units that mainly record shallowing (parasequences of Vail et al. 1991).

Based partly upon the stacking patterns of parasequences, or architecture, of portions of sedimentary sequences, stratigraphers have been able to recognize distinct groupings of facies within sequences, referred to as systems tracts. Briefly, these include lowstand (LST), transgressive (TST), highstand (HST), and falling stage (FSST, or regressive) systems tracts. The lowstand systems tract (LST) is



Fig. 5. Cherokee Unconformity (shown with arrows) between Upper Ordovician (Richmondian; Ashgill Stage) shales and overlying Lower Silurian (Llandovery; Rhuddanian) beds. A) Preachersville Shale Mbr. (Pr) of the Drakes Formation, sharply overlain by Belfast Member of Brassfield Formation (BB), lower massive cherty unit (BC); cut along KY Rte. 10, just west of Cahin Creek, Tollesboro, Lewis Co., KY. B) Queenston Shale (redbeds; Q) sharply overlain by white Whirlpool Sandstone (W); sharp flooding surface separates sandstone from overlying dark grey Power Glen (Cabot Head) Shale (PG), in turn sharply overlain by upper Medina Group (UM) reddish sandstones; West Jackson Street, Lockport, Niagara Co., NY.

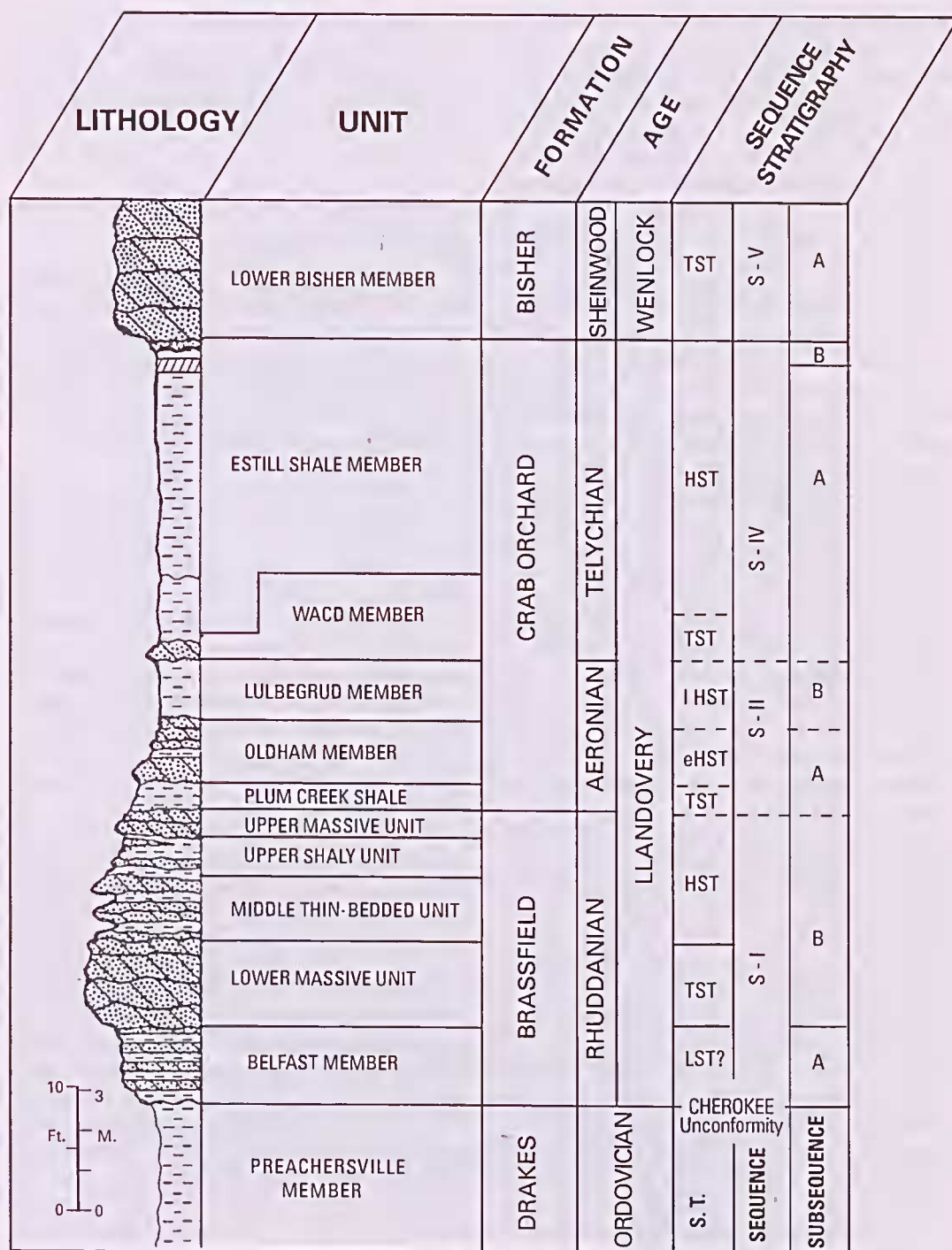


Fig 6. Generalized stratigraphic column and sequence stratigraphic interpretation for Lower Silurian (Llandovery) units in central Kentucky and south-central Ohio. Abbreviations: S.T.: systems tracts; LST: lowstand systems tract; TST: transgressive systems tract; eHST: early highstand systems tract; IHST: late highstand systems tract. Note that each major (third-order) sequence is divisible into sub-sequences (sensu Brett et al., 1990), or fourth order sequences, labeled A and B. Stratigraphic profile adapted from Gordon & Ettensohn (1984).

defined as sediments that accumulate between true lowest actual fall of sea level and the beginnings of more rapid rates of sea level rise; these deposits include non-marine channel fillings that may occur locally immediately above a sequence boundary or erosion surface. In deeper water areas turbidite fans are another potential expression of lowstand accumulation during times when sediments are flushed from shallow water areas into deeper water regions. However, in most shallow shelf and ramp settings there are no LST deposits and the transgressive surface is superimposed upon the erosional sequence boundary (Myers & Milton 1996; Catuneanu 2002).

The transgressive systems tract (TST) may show a sharp transgressive erosion surface at its base, referred to as a ravinement surface. This transgressive surface reflects relatively rapid onlap of marine waters over a broad area. In many cases, including most of the sequences discussed herein, the sequence boundary and transgressive surfaces are combined into a single erosion surface, the ET surface (Myers & Milton 1996). The transgressive systems tract (TST) itself shows a deepening upward, retrogradational stacking pattern of smaller scale cycles or parasequences, and is bounded at its top by a surface of maximum flooding. This surface, which may be very distinct in some sequences, represents a time of minimal sedimentation in offshore marine settings associated with rapid sea-level rise, drowning of coastlines, and sequestering of siliciclastic sediments in nearshore estuarine and lagoonal depositional settings. Maximum flooding surfaces in the Silurian of eastern North America are typically marked by distinct but thin lag accumulations, phosphatic nodules, oolitic ironstones, or corroded shells and conodont enrichments (Brett et al. 1998). Immediately underlying and overlying the maximum flooding surface is a thin, time-rich section referred to as a condensed section that represents strongly sediment-starved conditions at times of maximum deepening.

The highstand systems (HST) tract typically commences with deeper water deposits, such as dark shales, that sharply overlie the maximum flooding surface. The highstand systems tract reflects sedimentation during the late portion of sea level rise; HSTs may show a progradational succession of smaller parasequences, i.e., an overall shallowing-upward pattern. In many instances, the HST can be differentiated from a falling stage (FSST) or regressive phase, in which progradational stacking of parasequences reflects an abrupt overall upward-shallowing (Catuneanu 2003). Typically a sharp forced regres-

sion surface demarcates the base of the FSST, and, in some cases, a thin condensed lag bed may occur at this boundary (Brett 1995). The falling stage systems tract exhibits an overall shallowing and may be truncated at its top by the next major sequence boundary.

Description of Silurian Third Order Depositional Sequences

In the following sections the general sequence stratigraphy of the Lower Silurian in Ohio and Kentucky is described in ascending order and compared with reference sections in the north-central Appalachian Basin (Figs. 6, 7). The final section of this paper discusses the implications of revised stratigraphy for paleogeography, eustatic sea-level, and regional tectonics.

Sequence S-I. The first Silurian sequence (S-I) is the Medina or Tuscarora sandstone succession of the Appalachian Basin, which is recorded by the Lower Silurian (lower Llandovery) Brassfield Formation in Ohio and Kentucky (Figs. 5–7). It is bounded at its base by the Cherokee Unconformity (Fig. 5) and at its top by a more subtle and previously unrecognized sequence boundary marked by hematitic-phosphatic beds near the top of the Brassfield (Fig. 8). The equivalent sequence in western New York and Ontario consists of the Medina Group, comprising grey to reddish shales and sandstones (Brett et al. 1998; Fig. 7).

In the Cincinnati Arch region, the S-I basal unit is the Belfast Member of the Brassfield Formation (Fig. 8), an argillaceous dolostone and dolomitic shale that may resemble the underlying Drakes dolomitic shales. This interval apparently represents lowstand or initial transgressive conditions (Ettensohn 1992d). The basal bed of the Belfast Member is a massive, heavily bioturbated dolowackestone, 0.5 to 1 m thick; immediately above the sequence boundary the Belfast locally features a phosphatic, glauconitic lag. In central Kentucky this bed is a massive slightly glauconitic dolostone with spar filled burrow galleries near its top. The basal bed is sparsely fossiliferous, but contains scattered rugose corals and poorly preserved brachiopods. Locally it passes upward into a thin (0–0.5 m) interval of thin-bedded argillaceous dolostones and shales. The Belfast has been correlated with the Edgewood and Kankakee formations and, as with these units, is assigned an early Llandovery (Rhuddanian; sub-*Icriodina* Zone) age (Rexroad 1970; Berry & Boucot 1970). This

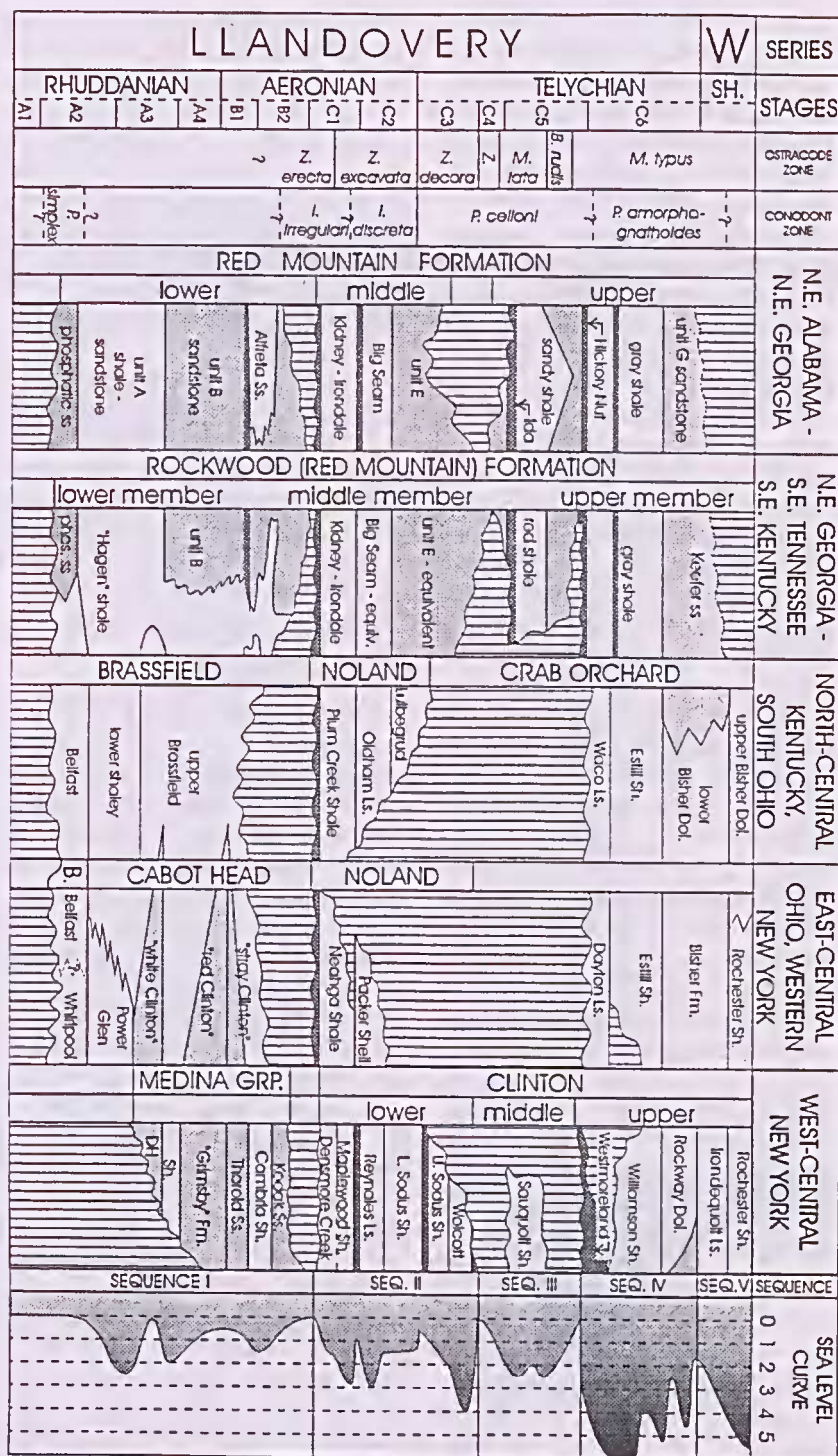


Fig 7. Correlation of Lower Silurian sequences in eastern USA; note particularly the comparisons of Kentucky, Ohio, and New York State. Curve on right side of diagram shows relative sea level curve for central New York State calibrated to benthic assemblages (BA-: shoreline, BA-2 above wave base; BA-3: average storm wavebase; BA-4 deep storm wavebase; see Brett et al. (1993) for discussion of depths of these assemblages. From Brett et al. (1998).

interval, together with the basal glauconitic bed, appears to form a transgressive-highstand couplet of a distinct minor (fourth-order) sequence, perhaps equivalent to the Whirlpool Sandstone in New York and Ontario (Fig. 5B). However, at the third-order scale this interval is interpreted to represent lowstand deposits of composite sequence S-I.

The next interval of the Brassfield Formation, (lower massive unit of Gordon & Ettensohn (1984) is a massive 1.5–3 m, orange buff-weathering crinoidal dolostone, typically with layers of light grey chert. The basal contact of the massive unit is sharp, and locally truncates some or all of the Belfast Member (Gordon & Ettensohn 1984; Fig. 8). This unit contains some fossils in common with the Manitoulin Formation of Ontario, its probable lateral equivalent. Both the Manitoulin and the bulk of the Brassfield Formation have been assigned to the Rhuddanian on the basis of conodonts of the *Icriodina irregularis* Zone (Rexroad 1970) and, in Ohio, brachiopods of the *Platymerella* Zone (Berry & Boucot 1970). Like the Manitoulin, the cherty Brassfield is interpreted as the upper portion of the TST of sequence S-I. The remainder of the Brassfield in southern Ohio and Kentucky consists of 8–10 m of thin-bedded, rippled dolostones that pass upward, into greenish grey shale and dolomitic siltstones, interpreted as tempestites (middle thin-bedded and upper shaly units of Gordon and Ettensohn 1984; Ettensohn 1992d; Fig. 8). This interval probably constitutes the HST of sequence S-I and corresponds to the Cabot Head Formation of northern Ohio, Michigan and Ontario. Locally, near Dayton, the lower portion of this succession contains moderate sized bioherms or mud mounds with abundant pelmatozoan holdfasts, bryozoans, corals, and stromatoporoids

(Lebold 2001; Schmieder & Ausich 2002). This occurrence indicates the buildup of bioherms during clean water conditions and rising sea level.

Sequence S-II. The second major Silurian sequence (S-II) is represented by a thin, poorly exposed succession assigned to the Noland or Crab Orchard formations (or groups) in southern Ohio and northern Kentucky, respectively (Figs. 6, 7). It corresponds to the lower part of the Clinton Group, mixed shales, carbonates and ironstones, in the Appalachian Basin (Figs. 7, 9).

The base of this sequence is represented by a dolostone unit that is capped by a hematitic bed rich in large discoidal pelmatozoan columnals, the so-called "Bead Bed" (Foerste 1935) or upper massive unit of the Brassfield (Gordon & Ettensohn 1984; Ettensohn 1992d; Fig. 8); this unit locally contains an abundance of the brachiopod *Cryptothyrella subquadrata* (formerly *Whitfieldella subquadrata*) and was mapped widely, as the "*Whitfieldella*" bed in central Kentucky by Foerste (1906). Most authors have included the "Bead Bed" as an uppermost unit in the Brassfield, but Gordon & Ettensohn (1984) recognized that it represents part of a distinct sequence. The base of this bed is sharply set off from the underlying shales of the uppermost Brassfield succession and represents the sequence boundary. We interpret the Bead Bed as a transgressive systems tract; the abundance of hematite and phosphatic nodules at the top of the interval indicates prolonged sediment starvation associated with maximum rates of sea level rise. This bed has a counterpart in the early Llandovery Densmore Creek phosphatic bed and Webster bed phosphatic conglomerate in New York State (LoDuca & Brett 1994; Fig. 9).

The main Plum Creek Member of the Noland Formation in southern Ohio and central Kentucky consists of about 1–2 m of greenish grey, sparsely fossiliferous shale, dated as late Rhuddanian to early Aeronian age (Berry & Boucot 1970); we equate this unit with the Maplewood-Neahga shales of western New York (Figs. 7, 9) and to the lowest tongue of the Rose Hill Shale in Pennsylvania. As with those units, the Plum Creek is sparsely fossiliferous, but passes laterally into skeletal limestones and becomes indistinguishable from the Oldham Limestone in the area of Berea, Kentucky (Foerste 1906). This suggests that the Plum Creek may represent an "in-board" or lagoonal shale, as is the Maplewood, that passes westward into offshore shoal carbonates (see LoDuca & Brett 1994).

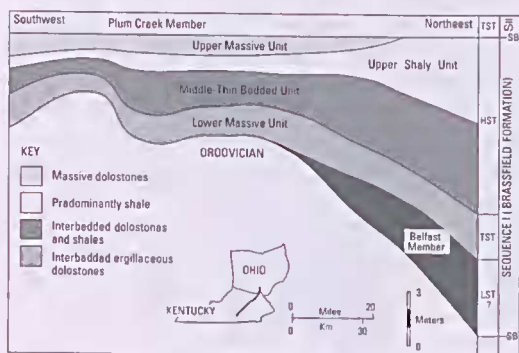


Fig. 8. Regional cross-section of the Brassfield Formation in southern Ohio and northern Kentucky, showing distribution of sub-units. Sequence stratigraphic abbreviations as in Fig. 6. Adapted from Gordon and Ettensohn (1984).

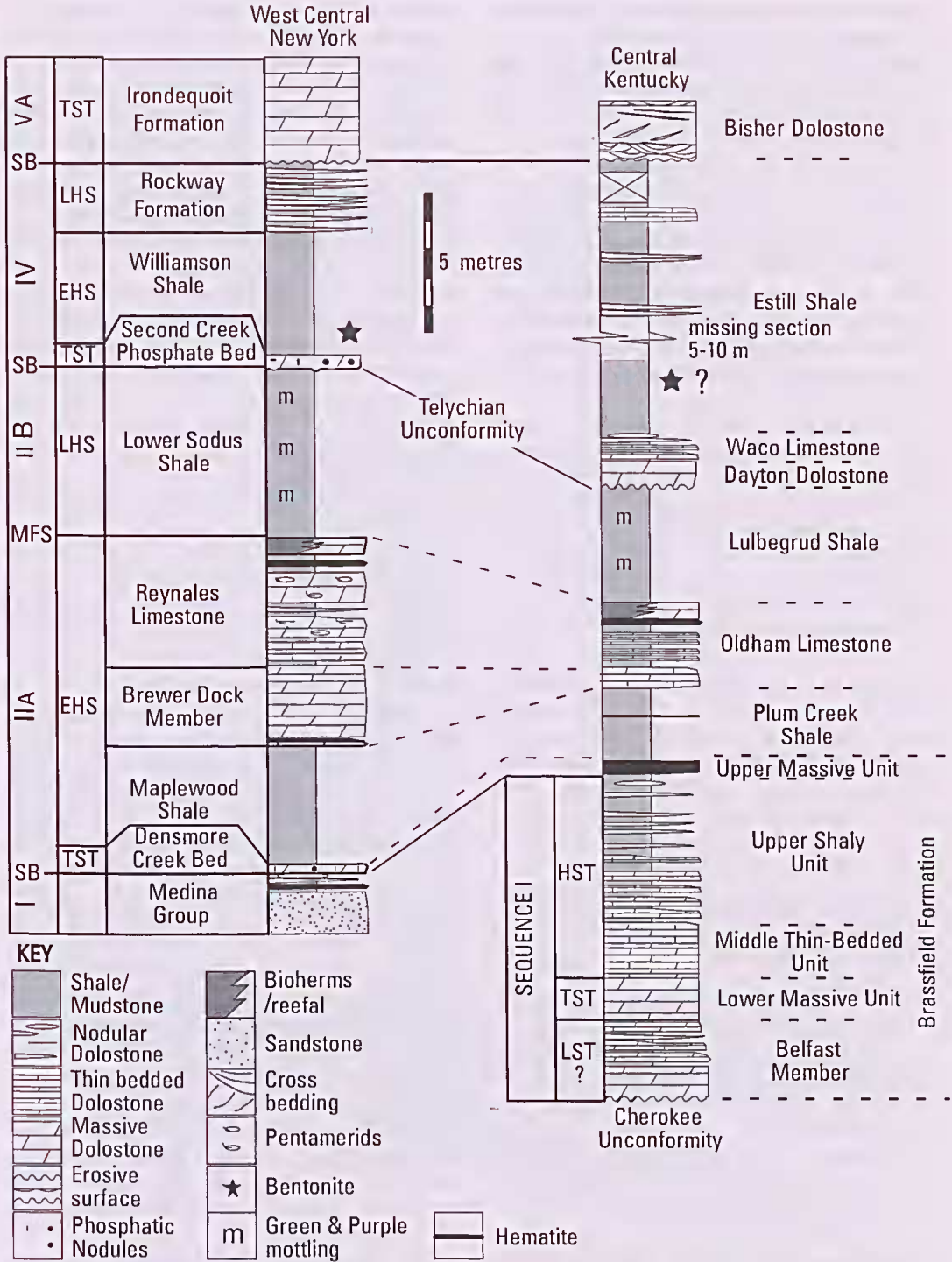


Fig 9. Comparison of Llandovery lithostratigraphic succession and inferred sequence stratigraphy in central New York State (vicinity of Rochester, NY) and central Kentucky/ southern Ohio. Sequence stratigraphic abbreviations as in Fig. 6.

Also included within sequence S-II in Ohio are the overlying Oldham Limestone and Lulbegrud Shale, which have been tentatively correlated with the Reynales Limestone and Sodus Shale of the classic New York section (Fig. 9; Lukasik 1988; Brett et al. 1990, 1998).

The Oldham Limestone comprises about 3–4 m of dolomitic wacke- and packstones, bearing a moderately diverse fauna. This limestone is dated as mid Llandovery Aeronian (C1–C2) age on the basis of conodonts (Kleffner 1990) and the brachiopod *Microcordinalia triplesiana* (formerly *Stricklandia triplesiana*; Berry & Boucot 1970). Ferruginous limestone below this bed may record a discontinuity, perhaps associated with the Sterling Station Iron Ore in the New York Clinton.

The Lulbegrud Shale is also about 3–4 m thick and comprises largely barren, greenish grey shale. This unit is poorly dated. Huddle (1967) reported *Neospathognathodus celloni* Zone conodonts from this unit suggesting a middle Telychian (C5) age, as in the Sodus Shale of New York (Fig. 9). Together, the Oldham Limestone and Lulbegrud Shale may represent the TST and HST, respectively, of a small-scale (fourth order) sequence.

Sequence S-IV In Ohio the Lulbegrud Shale, Oldham Limestone, and Plum Creek Shale are successively truncated to the northwest and overstepped by the Dayton Dolostone, a distinctive, thin, highly bioturbated glauconitic carbonate (Lukasik 1988; Fig. 10). In central Kentucky the Dayton interval is represented by the compact, basal, 30–60 cm, dolomitic limestone bed of the Waco Limestone Member (Figs. 9, 10). This bed is gradationally overlain by up to 2 m of thin bedded, highly fossiliferous limestone and shale near Irvine, Kentucky. Together, these beds of the Waco record a diverse and abundant fauna, especially rich in rugose and tabulate corals, including *Strombodes*, *Arachnophyllum*, *Chonophyllum*, and *Polyorophe*, some of which resemble those found in the late Llandovery of Ontario as well as in the Wenlock of England and Gotland (Foerste 1906).

The Dayton Dolostone has been dated as late Llandovery (mid-Telychian, N. celloni Zone) on the basis of conodonts (Kleffner 1990). The Dayton is thus approximately coeval with the Merrittton Limestone and upper Fossil Hill Dolostone, which similarly overstep strata of sequence S-II in the Bruce Peninsula area of southern Ontario, Canada (Stott & Von Bitter 1999; Fig. 7). Correlation of the Waco-

Dayton with the upper Fossil Hill is further supported by similarities in the coral fauna. This interval may correlate with the Westmoreland Iron Ore and equivalent Second Creek Phosphate bed in New York (Lin & Brett 1989; Brett et al. 1990). The Dayton-Waco carbonates are, correspondingly, interpreted as the TST of sequence S-IV; with sequence S-III (Sauquoit Shale), as well as upper parts of Sequence S-II (Wolcott Limestone), removed beneath the basal unconformity, as in western New York and Ontario (Lin & Brett 1988; Brett et al. 1990).

Brett et al. (1990) inferred that the sub-Dayton unconformity of central Ohio and the sub-Merrittton-Fossil Hill unconformity in Ontario are local manifestations of the same regional unconformity. It probably represents a minor episode of uplift and erosion along the Algonquin Arch, which was evidently active during the medial Silurian. Goodman & Brett (1994) suggested that this activity may reflect an isostatic response to thrust loading during early phases of the Salinic Orogeny (Fig. 3).

The HST of the fourth Silurian sequence (S-IV) is represented by the 10 to 20 m Estill Shale (a member of the Crab Orchard Formation in Kentucky terminology), which overlies the Dayton Limestone in the Dayton, Ohio region and the equivalent Waco Limestone in central Kentucky. (Figs. 7, 9).

In southern Ohio and northeastern Kentucky the Dayton-Waco carbonates appear to be absent and a thick shale (perhaps as much as 45 m thick in West Union, Ohio; Foerste 1906), mapped as the "Estill Shale", may actually be equivalent to both the Estill (*sensu stricto*) and the underlying Lulbegrud Shale (Fig. 11). Lower and upper units are separated by a subtle but regionally angular unconformity. The "lower Estill Shale" consists of purplish shales and contains an ostracode and conodont fauna suggestive of a mid Telychian age; this could correlate with either the upper Sodus Shale (sequence S-II) or the Sauquoit Shale (sequence S-III) of the New York succession (Brett et al. 1990, 1998). At the roadcut on the AA Highway near Charters, Kentucky (Fig. 11), a subtle but slightly angular discordance appears between the lower purplish shales and the overlying greenish-grey shales and siltstones of the upper Estill Formation (Mason et al. 1992a). At most, a thin transgressive lag deposit occurs at the base of sequence S-IV.

The upper Estill Shale is assigned a latest Llandovery (late Telychian) age on the basis of graptolites of the *Monograptus* cf. *M. clintonensis* Zone and conodonts of the *Pterospirifer* *amor-*

phognathoides Zone (Rexroad 1970; Kleffner 1987). The lower five meter interval of shale and thin, fossiliferous siltstones appears to correlate directly with the uppermost Rose Hill Shale of the Appalachian Basin and with the Williamson-Willowvale shales (sequence S-IV) of the standard New York section (Fig. 9). This represents the highest stand of relative sea level during the Silurian in eastern North America and appears to reflect a global eustatic highstand (Johnson 1996; Johnson et al. 1998).

The uppermost Estill dolomitic siltstone unit (previously assigned to the overlying Bisher Formation; Potter et al. 1991; Mason et al. 1992a,b), which

is regionally removed under the S-V unconformity at the base of the Bisher Dolostone, comprises thin- to medium-bedded dolomitic and somewhat fossiliferous carbonates, interpreted as tempestites (Aigner 1985; Mason et al. 1992a) and greenish-grey shales. This dolomitic siltstone appears to correlate directly with the Roekway Formation of Ontario and New York State and with the lower Keefer Sandstone or sandy uppermost Rose Hill Formation in Pennsylvania (late highstand of sequence S-IV; subsequence S-IVB; Figs. 6, 7, 9). To the northwest, near Dayton, Ohio, the Estill appears to grade into rhythmically bedded shale and dolomitic carbonate of the lower shale member of the Osgood Formation (Fig. 10).

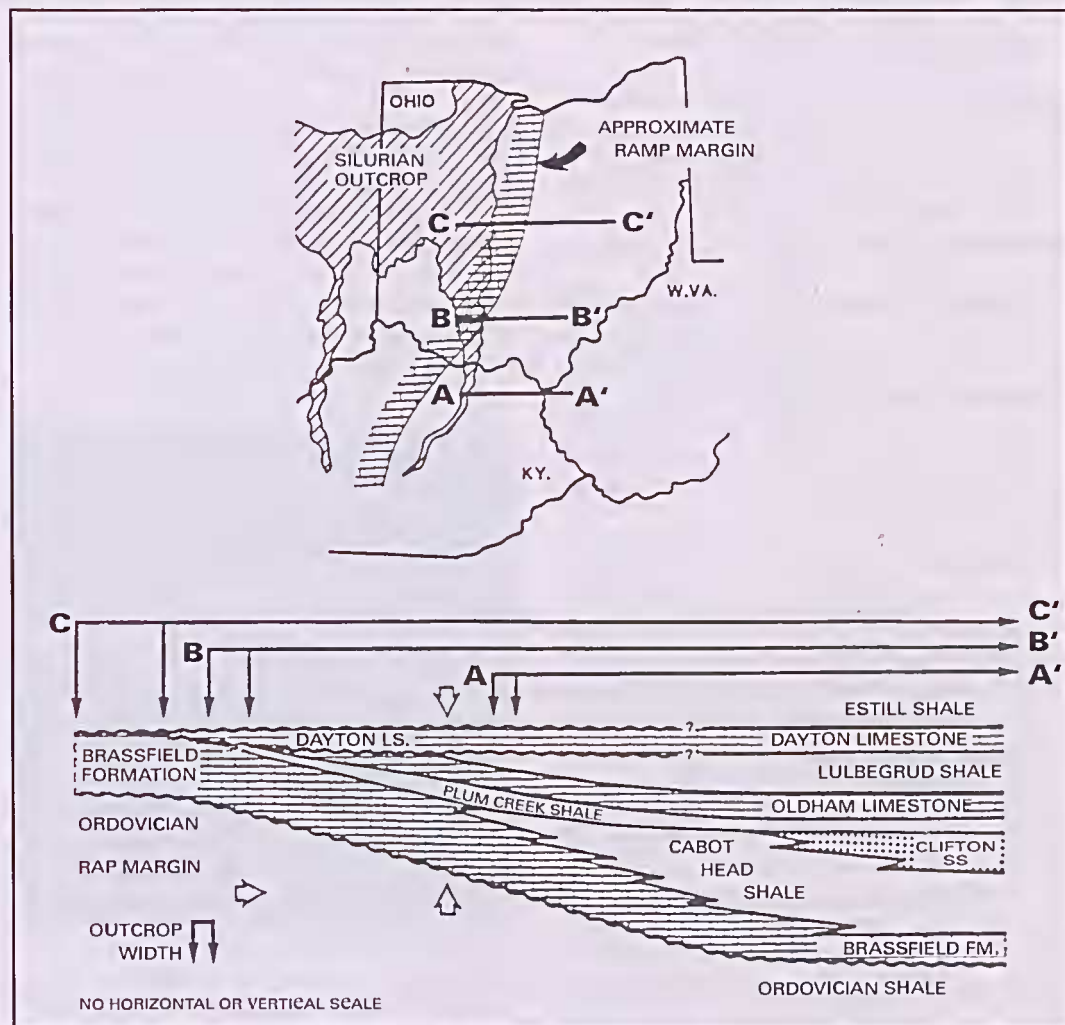


Fig 10. Regional cross sections of Silurian strata through south-central Ohio and northern Kentucky. Note the regional truncation of units along a proto-Findlay Arch (northwest or left side of cross section) below a major unconformity beneath the Dayton Limestone. Adapted from Lukasik (1988).

Also, probable K-bentonites have been found in this interval, which may correlate with beds in the Osgood Shale on western flank of the Cincinnati Arch (Ray & Brett 2001; Brett & Ray 2001). These ash beds may also correlate with K-bentonites found in the upper Llandovery of the southern Appalachians (Huff et al. 1997). Work on these beds is preliminary but appears promising. In particular a 1–3 cm greenish clay bed low in the Osgood Shale at Fairborn, Ohio appears to be traceable into outcrops of the Osgood in southern Indiana. It may also correspond to a bentonite reported from the upper Estill Shale at Charters, Kentucky (Mason et al. 1992a) and one or more thin yellowish weathering clay beds (probable K-bentonites) in the lower Williamson Shale at Rochester, NY (Brett et al. 1994).

Sequence S-V A very distinct sequence boundary at the base of the Bisher Dolostone separates overlying Sequence S-V from the underlying Estill Shale. At this surface, the uppermost Estill dolomitic siltstones and shales appear to be regionally truncated along a series of outcrops near Vanceburg, Kentucky (Figs. 7, 9, 12).

Sequence S-V shows a well-defined transgressive systems tract, recorded in erinoidal dolomitic packstones and grainstones, rich in the brachiopod *Whitfieldella oblonga*, now assigned to the lower unit of the as-yet undifferentiated Bisher Formation (Figs. 12–15). This interval has yielded conodonts indicating a *Spathognathodus ramuliformis* Zone age (Rexroad 1970; Berry & Boucot 1970; Kleffner 1989, 1991); this bed is aligned with the similarly dated erinoidal grainstones of the Irondequoit Formation in western New York (Rexroad & Rickard 1965). The top of the lower Bisher unit is thus interpreted as a major flooding surface corresponding to the upper glauconitic condensed bed of the Irondequoit Limestone in western New York. This is sharply overlain by a thin shaly HST interval, termed Massie Shale in the Dayton, Ohio area, apparently correlative with the Rochester Shale in the Appalachian Basin (Figs. 12, 13). This interval also correlates with the thin upper shale unit of the Osgood Member in Indiana, which has yielded a fauna of brachiopods, bryozoans and echinoderms very similar to those of the Rochester Shale in New York (Frest et al. 1999). No more than a half-meter of shales and thin calcisiltites occurs at this level in Kentucky. However, to the north, near Hillsboro, Ohio, a succession of nearly three meters of typical Massie (=“Rochester”) Shale overlies the basal

grainstones of the Bisher Dolostone. The succession thins again toward Dayton, Ohio (Figs. 13, 14).

A very interesting laminated dolostone bed up to 1 m thick overlies the “Massie” shale interval. Locally, as near Peebles, Ohio, this bed shows strong ball-and-pillow style deformation. The interval very closely resembles the DeCew Dolostone, which sharply overlies the Rochester Shale in western New York and Ontario (Figs. 12, 15). In all of its outcrops the DeCew is similarly heavily deformed. We suggest that the contorted beds in the upper Bisher/Massie units and the DeCew Dolostone represent coeval, sandy, detrital carbonate facies associated with a forced regression; i.e., they represent the falling stage systems tract of sequence V, and their typically sharp base indicates a forced regression surface. Moreover, the occurrence of deformation in this interval over a vast region suggests that these beds record extremely large seismic shocks. Pope et al. (1997) and McLaughlin & Brett (2004) documented similar very widespread deformation in similar regressive detrital carbonates in the Ordovician of Kentucky. We suggest that these widespread deformed beds record not only appropriate (“deformation-prone”) facies, but also a “trigger” provided by seismic shocks. Such seismites may provide very useful regional event stratigraphic markers (Pope et al., 1997; McLaughlin and Brett, 2004).

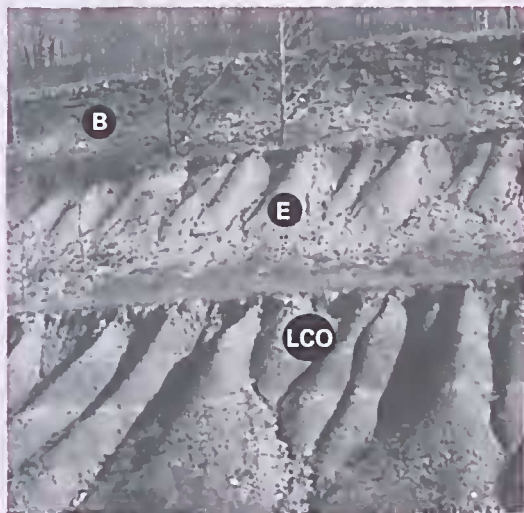


Fig 11. Roadcut section along AA Highway (KY Rte. 9/10) at Charters, Lewis Co., KY showing Crab Orchard Shale overlain by Bisher Dolostone (B), near top of view. Lower Crab Orchard beds are maroon shales with thin siltstones and possible K-bentonite showing apparent slight discordance with overlying lighter greenish grey (Estill) shale. Height of cut is approximately 25 m.

Sequence S-VI. The remainder of the Bisher Formation contains a complex facies mosaic, the details of which are somewhat obscured by dolomitization (Mason et al. 1992b). A cryptic, but

important, sequence boundary occurs above the Massie calcisiltite and shale interval. This sequence boundary appears to correlate with the base of the Lockport Group and the base of the McKenzie





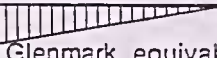

SUBSE	DEPO. PHASE	OHIO	W. NEW YORK	CENTRAL PENNSYLVANIA	
VI-D			GULEPH DOL.	BLOOMSBURG FM.	
VI-C		 ? ? ? PEEBLES DOL.	ERAMOSA DOL.	MCKENZIE SHALE and LIMESTONE	unnamed shale/ls. ?? Rabble Run tongue (red sh.)
VI-B	HST	LILLEY PEEBLES SH.	V		unnamed sh./ls. mbr.
	TST	u. LILLEY	GOAT ISLAND DOL. A NF		unnamed ls. mbr.
VI-A	HST	u. LILLEY DOL./SH. (reefal)	u. GASPORT DOL.		unnamed thrombolite mbr.
	TST	l. LILLEY DOL.	l. GASPORT DOL.		unnamed Whitfieldella bed
V-C	HST			MCKENZIE SHALE and LIMESTONE	
	TST	MASSIE SHALE	DECEW DOL.		Glenmark equivalent DeCew equivalent
V-B	HST		U. ROCHESTER SH.	U. ROCHESTER SH.	
	TST	MASSIE SH.		unnamed limestone	
V-A	HST	BISHER/MASSIE	L. ROCHESTER SH.	L. ROCHESTER SH.	
	TST	BISHER DOL.	IRONDEQUOIT LS.	upper KEEFER SS. l. KEEFER SS.	
IV-B	HST	ESTILL FM. UPPER ESTILL SH.	ROCKWAY DOL.	ROSE HILL SH.	uppermost shale / siltstone
	TST		SALMON CREEK BED		Salmon Creek bed-equivalent
IV-A	HST	LOWER ESTILL SH.	WILLIAMSON SH.		upper shaly mor.
	TST	DAYTON-WACO DOL.	MERRITTON / S.C.		unnamed equiv. ls./hem. upper shaly mbr. Center Mbr. Ss.

Fig 12. Summary of correlation of upper Llandovery-Wenlock units in central Ohio, New York State/Ontario, and Pennsylvania. Abbreviations for members of Goat Island Formation: NF: Niagara Falls (massive dolostone); A: Ancaster (cherty dolostone) Member; Member; V: Vincemount (shaly dolostone) Member; SC: Second Creek phosphate bed of Williamson shale; terminology of Brett et al. (1995).

Formation in Pennsylvania and Maryland and represents the base of sequence S-VI (Figs. 8, 12). This interval is represented by hummocky to herringbone cross-stratified, erinoidal dolostones, assigned to the upper Bisher Formation in Kentucky and to the Bisher or lower Lilly Formation in Adams County, Ohio (Figs. 14, 15; Ausich 1987; Kleffner & Ausich 1988; Kleffner 1990). Local abrupt changes in thickness and facies within this succession are typical (Mason et al. 1992a,b) and may represent the development of a series of skeletal megashoals and intershoal areas during this part of Wenlock time (Pratt & Miall 1993). The top of this succession contains a distinctive, poorly bedded interval that appears as a series of mounds or blocks of dolomierite surrounded by poorly bedded dolomitic mudstones. This interval has been interpreted as a collapse breccia associated with karstification during the Devonian because it lies just below the Kaskaskia unconformity in several locations. However, close examination of the mounds revealed the presence of heavily dolomitized corals, stromatoporoids and erinoid holdfasts. Thus, we interpret the mounds as bioherms (Fig. 14). This interval thus appears to be a continuation of the Gasport biohermal interval, widely distributed in the Appalachian Basin in western New York and Ontario (Crowley 1973; Smosna & Patchen 1992; Fig. 15). At Hillsboro, Ohio it appears that this interval passes laterally into a greenish shaly dolostone and shale interval that we would correlate with the upper or Pekin Member of the Gasport Formation (Brett et al. 1990). Just why biohermal buildups are so prolific at this horizon is poorly understood but we suggest a combination of low siliciclastic sedimentation during an episode of

gradual sea level rise (Crowley 1973; Smosna & Patchen 1992).

The overlying upper Lilly Dolostone succession of southern Ohio comprises massive erinoidal dolostone, locally with chert nodules; this interval appears to grade laterally to the northwest into the Cedarville Dolostone near Dayton, Ohio (Fig. 14). This interval has yielded conodonts of the *Ozarkodina sagitta rhenana* Zone (Kleffner, 1990); it is lithologically similar to the correlative lower Goat Island Dolostone (Niagara Falls, and Ancaster cherty members of Brett et al. 1995) in western New York and Ontario. A shaly interval identified as the "Lilly-Peebles transition", in south-central Ohio (Ausich 1987; Kleffner and Ausich, 1988) records a distinct deepening event. We tentatively correlate this interval to shaly dolostone and shale of the Vinemount Member in Ontario and western New York (Brett et al. 1995), and possibly to the Waldron Shale of Indiana and Kentucky. A preponderance of shale during this interval throughout much of eastern North America, may suggest a deepening and influx of siliciclastics associated with the second tectophase of the Salinic Orogeny (Ettensohn & Brett 1998); alternatively it may record a widespread late Wenlock eustatic highstand (Johnson et al. 1998).

The Peebles Dolostone, the highest Silurian unit present in south-central Ohio, consists of massive vuggy dolostone that may relate to the Eramosa Dolostone of Ontario. The contact of this unit on the underlying shales is sharp, and probably represents the VII sequence boundary (Brett et al. 1995). However, the biostratigraphy of the Lilly-Peebles and Peebles interval requires further study to test these correlations.

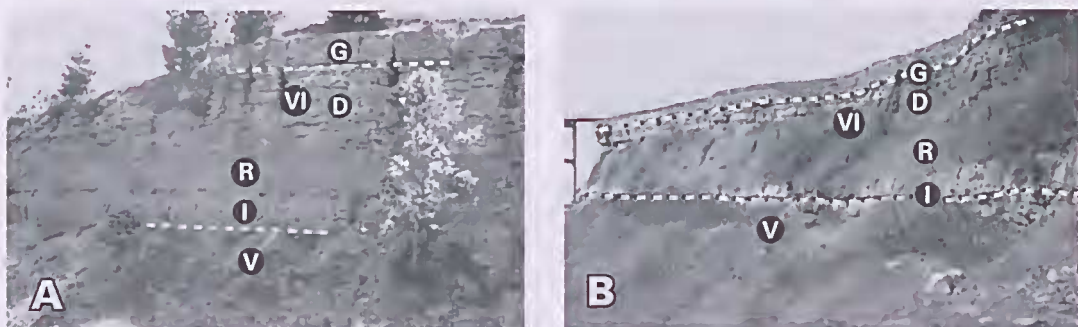


Fig. 13. Comparative stratigraphy of sequences S-V and S-VI in Ohio and New York. A) section of upper Estill and Bisher formations; Rochester Shale equivalent R is about 3 m thick; roadcut along US Rte. 62 just south of Hillsboro, Highland Co., Ohio. Note comparable succession of units in Ohio correlative with those of western New York. B) Upper Clinton and Lockport Groups; Rochester Shale is approximately 20 m thick. Niagara Gorge near Lewiston, Niagara Co., NY. Symbols for New York units and their probable equivalents in Ohio include: I: Irondequoit Limestone; R: Rochester Shale; D: DeCew Dolostone; G: Gasport Limestone. Two sequence boundaries are present here marked V and VI (note arrows).

The upper Lilly to Peebles interval has been largely removed by Devonian erosion in northern Kentucky. Toward Dayton, however, higher Silurian units, as well as Middle Devonian beds emerge as this unconformity becomes less prominent. In the southeastern part of the study area grey to black pyritic shales of the Upper Devonian (Famennian) are juxtaposed directly upon eroded Silurian carbonates (see Fuentes et al. 2001). The unconformity typically displays a small amount of relief and may be overlain by a thin lag deposit of dark bone and conodont-rich pyritic to phosphatic limestone. Corrosion and some dissolution of the underlying Silurian carbonates is typical.

Figure 14 illustrates a northwest-southeast correlated cross section based upon four major outcrops at Fairborn, Ohio to Herron Hill, Kentucky; terminology follows Ausich (1987) and Kleffner & Ausich (1988). A similar succession of units is present over this region, although similarities have been masked by different terminology and offset of contacts:

A) ("Laurel"-lower Bisher Fm.) a lower compact, massive erinoid brachiopod-rich limestone/dolostone rests sharply on shales or shaly dolostones, and is overlain by B) (Massie Shale) soft, medium to dark grey shales and/or argillaceous dolostones, capped, in turn, by C) (part of Massie Shale) laminated to hummocky cross stratified dolomitic siltstone or silty-sandy dolostone typically with internal deformation. The latter is sharply overlain by D) (Euphemia, upper Bisher Fm.) massive, cross bedded, sandy erinoid dolostone which grades upward into E) (Springfield-upper Bisher Fm.) thin bedded dolostones with dolomitic shale

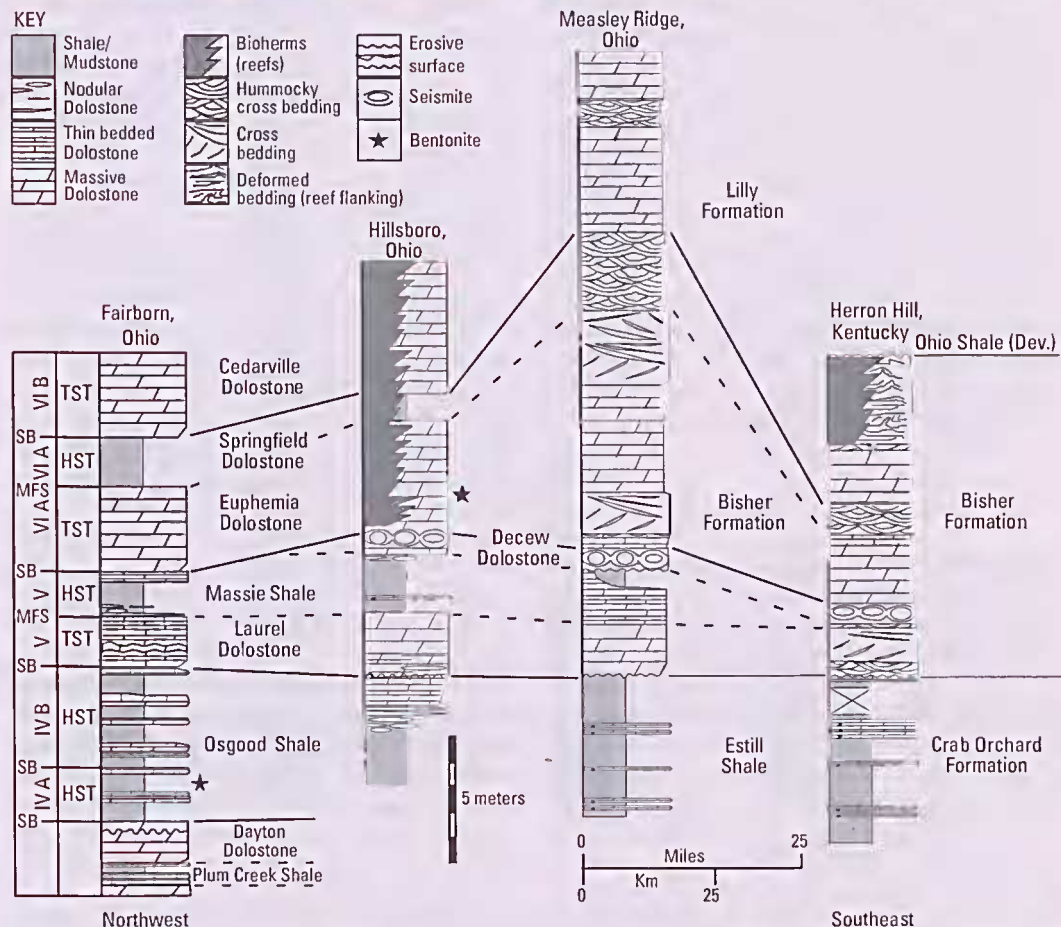


Fig 14. Correlated stratigraphic columns along NW-SE cross-section from Fairborn Quarry just SE of Dayton, Ohio to Herron Hill, Lewis Co., Kentucky. Approximate position of cross section shown in Figure 2. Note comparison of New York-Ontario terminology shown in Fig. 15. Sequence stratigraphic abbreviations as in Fig. 6.

partings, sharply overlain by F) (Cedarville, Lilly Fm.) more massive erinoidal dolostones with local stromatoporoid biostromes and micritic mounds; G) (Lilly, upper Bisher Fm.) local cherty bioturbated dolomierite; and, finally, H) (Lilly-Peebles transition) shaly dolostone and dolomitic shales, which locally contain bioherms.

The successions in Ohio and Kentucky can be correlated unit for unit with those of the latest Llandovery to Wenlock succession of New York and Ontario, Canada (Figs. 12, 15), as follows: Unit A: Irondequoit Limestone; Unit B) Rochester Shale (partially truncated by erosion to the west in Ontario); Unit C: DeCew Dolostone (a possible widespread seismite); Unit D: lower Gasport Limestone (Gothic Hill Member), erinoidal dolomitic grainstone; Unit E: upper Gasport (Pekin Member), thinly bedded dolostones and bioherms; Unit F: lower Goat Island Formation (Niagara Falls Member), massive erinoidal dolostone; Unit G: middle Goat Island (Ancaster Member) medium to thin bedded cherty dolomierite; and Unit H: upper Goat Island (Vinemount Member), dolomitic shale and shaly dolostone. In turn, these units represent components (mainly systems tracts) of regionally widespread depositional sequences and subsequences: Unit A: TST of S-V; Unit B: HST of S-V; Unit C: FSST of subsequence S-V (and base of a subsequence); Unit D TST of subsequence S-VIA; Unit E: HST of S-VIA; Units F, G, TST of S-VIB; and Unit H: HST of S-VIB (Fig. 12; see Brett et al. 1990, for definition and discussion of these sequences).

SUMMARY DISCUSSION

Despite a multiplicity of names applied to medial Silurian units in different regions along the eastern to northern flank of the Cincinnati, this area displays the same basic succession of units and indeed, this succession can be matched rather closely with the coeval interval in the Appalachian Basin. The lateral persistence of sequences and their bounding surfaces over much of northeastern to central North America strongly suggests an alloeyelic, probably eustatic sea level control on the development of these sequences. However, the local expression of the sequences and their bounding surfaces was modified by far-field tectonics, notably gentle uplift and migration of the Findlay-Algonquin Arch, influenced by lithospheric flexure (Beaumont et al. 1988).

The medial Silurian succession along the eastern flank of the Cincinnati Arch in south-central Ohio, is most comparable to that exposed along the Niagara Escarpment in southern Ontario, Canada and western New York. The similarities of facies and thickness patterns probably reflect the fact that these widely separated areas lay more or less along the same NE-SW trending depositional strike belt.

During Wenlock time the Findlay-Algonquin Arch system was oriented northeast-southwest from near Hamilton, Ontario to southwestern Ohio (Figs. 2, 10). Both the outcrops in southern Ontario and those of south central Ohio represent facies deposited to the southeast of the arch. The Brassfield Dolostone maintains similar thickness and only minor facies change across this region, suggesting that no major positive feature was present in early Llandovery time. However, regional eut out of Sequences S-I to S-III toward the northwest in both New York-southern Ontario and south central Ohio reflects erosional truncation of units along the arch, a probable forebulge that became uplifted during later Llandovery time (Lukasik 1988; Brett et al. 1990). This eut out appears to occur beneath a widespread glauconitic-bioturbated dolostone, the Merrittton Dolostone of Ontario and equivalent Dayton Formation in Ohio. Likewise, the thinning and increased carbonate content of the Estill-Osgood interval and sharpening of the contacts from Hillsboro northwest to Fairborn, Ohio reflects a generally positive area in the Findlay-Algonquin Arch (northeast branch of Cincinnati Arch). However, the thickness of the Estill Shale in central Ohio and northern Kentucky more resembles that of the Williamson-Willowdale interval in central New York State, suggesting an abrupt shift in the angle of orientation of the basin axis in late Telychian time (cf. Ettensohn & Brett 1998; Ettensohn 2004). This change in geometry will be discussed more fully in a forthcoming paper.

Not so readily explained is the apparent condensation of sequences S-V and S-VI and the eut out of unit D (Massie-Rochester Shale) to the southeast in northern Kentucky. This suggests the development of a secondary arch to the southeast of the Cincinnati or Findlay arch. In later Silurian and Devonian time this southeastern area becomes the region of maximum truncation. Thus, for example, in areas to the southeast of Vaneeburg, Upper Devonian black shales rest successively upon the Bisher, Estill, Brassfield and finally on Upper Ordovician formations. This effect has been attributed to the rise of

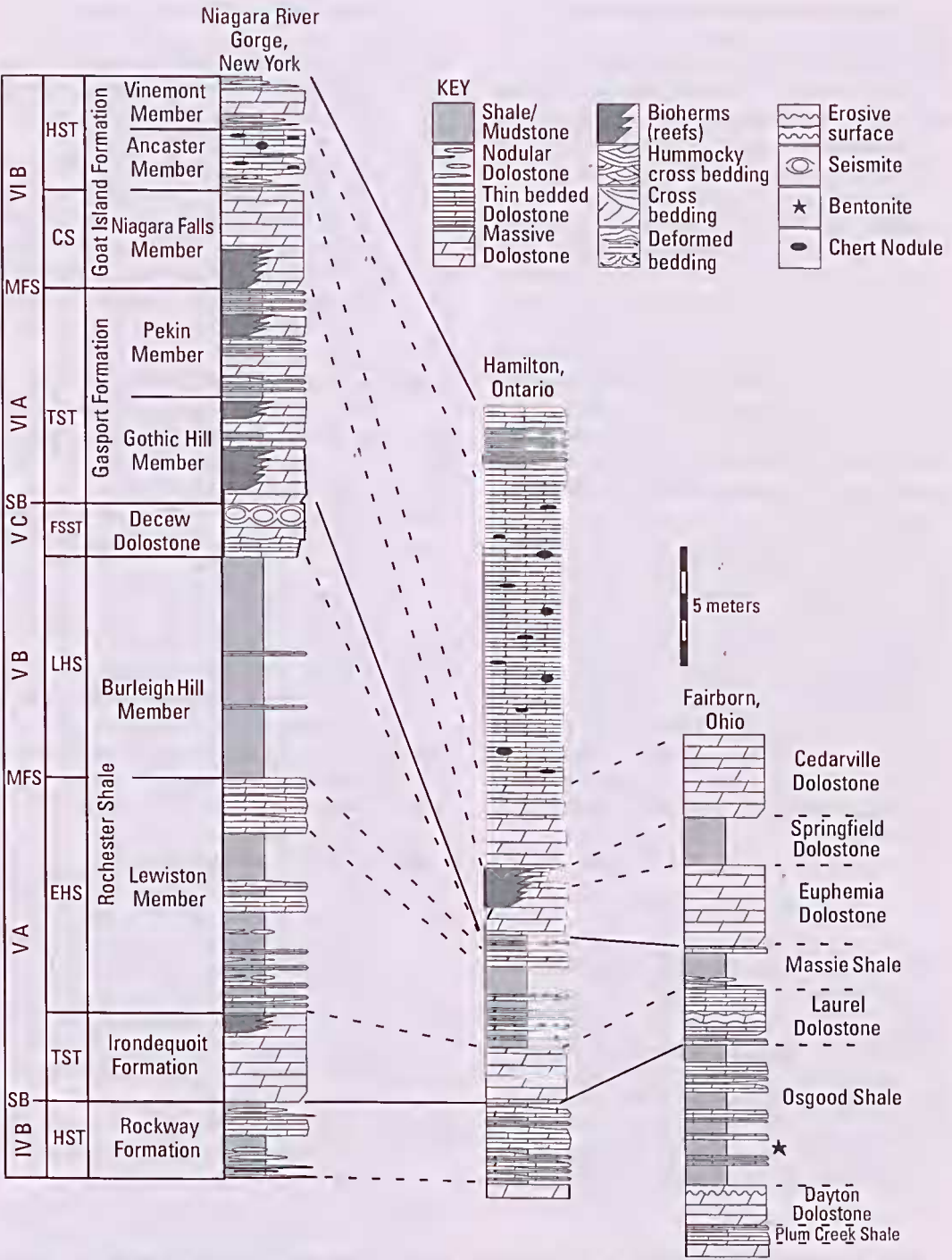


Fig 15. Correlation of late Llandovery to Wenlock stratigraphy of Niagara Gorge, New York, Hamilton, Ontario, and Dayton, Ohio. Sequence stratigraphic abbreviations as in Fig. 6.

the "Cincinnati Arch" during Siluro-Devonian time, although, in fact, it is clear that this positive area was positioned well to the southeast of the present Cincinnati Arch. In any case, it is now apparent that arching in the southeast must have commenced during Wenlock time. The Estill Shale (latest Llandovery) does not appear to have been strongly affected by this arching and indeed thickens to the southeast. Conversely, the Massie-Rochester Shale is largely truncated by the sub-sequence S-VC and/or basal S-VI erosion surfaces in the vicinity of Vanceburg, Kentucky. It is not clear at this time what the exact orientation of the northern Kentucky positive area was, nor how far northward this arch extended. It does not appear in the western New York or Pennsylvania outcrop belts. Further study of subsurface relationships will be needed to clarify these relationships, but these will be aided by the extension of a detailed sequence and event stratigraphic framework.

Finally, both the occurrence of an extremely widespread seismite (DeCew horizon) and newly discovered K-bentonites indicates both seismic and volcanic activity within or at the periphery of the Appalachian foreland basin. This evidence, together with evidence for restructuring and/or migration of arches (forebulges; Beaumont et al. 1988; Ettensohn & Brett 1998; Ettensohn 2004) during the latest Llandovery to Wenlock, indicates renewed active tectonism within the medial Silurian as previously postulated (Goodman & Brett 1994; Ettensohn & Brett 1998).

ACKNOWLEDGMENTS

We thank Warren Huff, Greg Edgecombe, John Talent, and Ruth Mawson for reviewing this paper and suggesting improvements. Mark Kleffner shared unpublished observations on conodont biostratigraphy; Sean Cornell and Pat McLaughlin provided important assistance in the field. Tim Phillips helped in numerous ways in the final preparation of figures. Funding for this research was partially supported by a start-up grant from the University of Cincinnati.

REFERENCES

- AIGNER, T., 1985. *Storm Depositional Systems: Dynamic Stratigraphy in Modern and Ancient Shallow Marine Sequences, Lecture Notes in the Earth Sciences* 3. Springer, Berlin, 174 pp.
- AUSICH, W.I., 1987. John Bryan State Park: Silurian Stratigraphy. *Geological Society of America DNAG Centennial Field Guide, North Central Section*, p. 419–422.
- BEAUMONT, C., QUINLAN, G. & HAMILTON, Z. J., 1988. Orogeny and stratigraphy: Numerical models of the Paleozoic in the eastern interior of North America. *Tectonics* 7: 389–416.
- BERRY, W.B.N. & BOUCOT, A.J., 1970. Correlation of the North American Silurian rocks. *Geological Society of America Special Paper* 102: 1–289.
- BRECHLEY, P.J., 2004. End Ordovician glaciation. In *The Great Ordovician Biodiversification Event*. B.D. Webby, F. Paris, M.L. Droser & I.G. Percival, eds, Columbia University Press, New York, 81–83.
- BRECHLEY, P.J., MARSHALL, J.D., CARDEN, G.A.F., ROBERTSON, D.B.R., LONG, D.G.F., MEIDI, T., HINTS, L. & ANDERSON, T.F. 1994. Bathymetric and isotopic evidence for a short-lived Late Ordovician glaciation in a greenhouse period. *Geology* 22: 295–298.
- BRETT, C.E., 1995. Sequence stratigraphy, biostratigraphy, and taphonomy in shallow marine environments. *Palaios* 10: 597–616.
- BRETT, C.E., 1998. Sequence stratigraphy, paleoecology, and evolution: Biotic clues and responses to sea-level fluctuations. *Palaios* 13: 241–262.
- BRETT, C.E., BAARLI, B.G., CHOWNS, T., COTTER, E., DRIESE, S., GOODMAN, W. & JOHNSON, M.E., 1998. Early Silurian condensed horizons, ironstones, and sequence stratigraphy in the Appalachian foreland basin. In *Silurian Cycles: Linkages of Dynamic Stratigraphy with Atmospheric, Oceanic, and Tectonic Changes*, E. Landing & M.E. Johnson, eds, New York State Museum Bulletin 491: 89–143.
- BRETT, C.E., BOUCOT, A.J. & JONES, B., 1993. Absolute depths of Silurian benthic assemblages. *Lethaia* 26: 25–40.
- BRETT, C.E., GOODMAN, W.M. & LODUCA, S.T., 1990. Sequences, cycles, and basin dynamics in the Silurian of the Appalachian foreland basin. *Sedimentary Geology* 69: 191–244.
- BRETT, C.E., GOODMAN, W.M. & LODUCA, S.T., 1994. Ordovician and Silurian strata in the Genesee Valley area: Sequences, cycles, and

- facies: *New York State Geological Association Field Trip Guidebook*. 66th Annual Meeting, Rochester, New York 381–442.
- BRETT, C. E. & RAY, D.C., 2001. Sequence and event stratigraphy of the Medial Silurian of Eastern North America: comparisons of Appalachian Basin and Cincinnati Arch successions. *Geological Society of America Abstracts with Programs* 33 (1): A-16.
- BRETT, C.E., TEPPER, D.H., GOODMAN, W.M., LODUCA, S.T. & LIN, B.Y., 1995. Revised stratigraphy and correlation of the Niagara Provincial Series (Medina, Clinton, and Lockport groups) in the type area of western New York. *U.S. Geological Survey Bulletin* 2086: 1–66.
- CATUNEANU, O., 2002. Sequence stratigraphy of elastic systems: concepts, merits, and pitfalls. *Journal of African Earth Sciences* 35: 1–43.
- CROWLEY, D. J., 1973. Middle Silurian patch reefs in the Gasport Member (Lockport Formation), New York. *American Association of Petroleum Geologists Bulletin* 57: 283–300.
- COE, A.L. & CHURCH, K.D., 2003. Sequence stratigraphy. In *The Sedimentary Record of Sea-Level Change*, A.L. Coe, ed, Cambridge University Press, 57–98.
- DENNISON, J.M. & ETTENSOHN, F.M., eds, 1994. Tectonic and Eustatic Controls on Sedimentary Cycles. *Society for Economic Paleontologists and Mineralogists, Concepts in Sedimentology and Paleontology* 4: 181–201.
- DENNISON, J.M., & HEAD, J.M., 1975. Sea-level variations interpreted from the Appalachian Basin Silurian and Devonian. *American Journal of Science* 275: 1089–
- EMERY, D. & MYERS, K.J., eds., 1996. *Sequence Stratigraphy*. Blackwell, Oxford, 297pp.
- ETTENSOHN, F.R., 1991. Flexural interpretation of relationships between Ordovician tectonism and stratigraphic sequences, central and southern Appalachians, U.S.A. In *Advances in Ordovician Geology*, C.R. Barnes & S.H. Williams, eds, *Geological Survey of Canada Paper* 90-9, 213–224.
- ETTENSOHN, F.R., 1992a. *Changing Interpretations of Kentucky Geology: Layer Cake, Facies, Flexure, and Eustasy*. Ohio Division of Geological Survey, *Miscellaneous Report* 5, 184 pp.
- ETTENSOHN, F.R., 1992b. Basic flexural models. In *Changing Interpretations of Kentucky Geology: Layer Cake, Facies, Flexure, and Eustasy*, F.R. Ettensohn, ed, Ohio Division of Geological Survey, *Miscellaneous Report* 5, 9–12.
- ETTENSOHN, F.R., 1992c. General Ordovician paleogeographic and tectonic framework for Kentucky. In *Changing Interpretations of Kentucky Geology: Layer Cake, Facies, Flexure, and Eustasy*, F.R. Ettensohn, ed, Ohio Division of Geological Survey, *Miscellaneous Report* 5, 19–21.
- ETTENSOHN, F.R., 1992d. Upper Ordovician-Lower Silurian rocks at Cabin Creek, northeastern Kentucky. In *Changing Interpretations of Kentucky Geology: Layer Cake, Facies, Flexure, and Eustasy*, F.R. Ettensohn, ed, Ohio Division of Geological Survey, *Miscellaneous Report* 5, 159–164.
- ETTENSOHN, F.R., 2004. Modeling the nature and development of major Paleozoic elastic wedges in the Appalachian Basin, USA. *Journal of Geodynamics* 37: 657–681.
- ETTENSOHN, F.R. & BRETT, C.E., 1998. Tectonic components in Silurian cyclicity: Examples from the Appalachian Basin and global implications. In *Silurian Cycles: Linkages of Dynamic Stratigraphy with Atmospheric, Oceanic, and Tectonic Changes* E. Landing, E. & M.E. Johnson, eds, *New York State Museum Bulletin* 491: 145–162.
- Ettensohn, F.R. & Brett, C.E., 2002. Stratigraphic evidence from the Appalachian Basin for continuation of the Taconian Orogeny into Silurian time. In *Taconic Convergence: Orogen, Foreland Basin and Craton*, C.E. Mitchell & R. Jacobi, eds, *Physics and Chemistry of the Earth* 27, 279–288.
- ETTENSOHN, F.R. & PASHIN, J.C., 1992. A brief structural framework of Kentucky. In *Changing Interpretations of Kentucky Geology: Layer Cake, Facies, Flexure, and Eustasy*, F.R. Ettensohn, ed, Ohio Division of Geological Survey, *Miscellaneous Report* 5, 6–9.
- FOERSTE, A.F., 1906. The Silurian, Devonian, and Irvine formations in east-central Kentucky. *Kentucky Geological Survey Bulletin* 7: 369 pp.
- FOERSTE, A.F., 1935. Correlation of Silurian formations in southwestern Ohio and southeastern Indian, Kentucky, and western Tennessee. *Bulletin, Scientific Laboratory, Denison University* 30: 119–205.

- FREST, T.J., BRETT, C.E. & WITZKE, B., 1999. Caradocian to Gedinian echinoderm associations of central and eastern North America. In: *Palaeocommunity Analysis: A Silurian-Lower Devonian Example*, A.J. Boucot & J.D. Lawson, eds, Cambridge University Press, 638–783.
- FUENTES, S., OVER, D.J. & BRETT, C. E., 2001. Conodont biostratigraphy of "Olenangy" Shale in northeastern Kentucky. In: *Sequence, Cycle, and Event Stratigraphy of Upper Ordovician and Silurian Strata of the Cincinnati Arch Region*. T.J. Algeo & C.E. Brett, eds, *Kentucky Geological Survey Guidebook 1*, Kentucky Geological Survey, Lexington, Kentucky, p. 136–140.
- GOODMAN, W.M. & BRETT, C.E., 1994. Tectonic vs. eustatic controls on the stratigraphic architecture of the Silurian, northern Appalachian Basin. In *Tectonic and Eustatic Controls on Sedimentary Cycles: Society of Economic Paleontologists and Mineralogists, Concepts in Sedimentology and Paleontology*, J.M. Dennison & F.M. Ettensohn, eds, 4: 147–169.
- GORDON, L.A. & ETTENSOHN, F.R., 1984. Stratigraphy, depositional environments, and regional dolomitization of the Brassfield Formation (Llandoveryan) in east-central Kentucky. *Southeastern Geology* 25: 101–115.
- GRAHN, Y. & CAPUTO, M., 1992. Early Silurian glaciation in Brazil. *Palaeogeography, Palaeoclimatology, Palaeoecology* 99: 9–15.
- HAQ, B.U., HARDENBOL, J. & VAIL, P.R., 1987. Chronology of fluctuating sea-levels since the Triassic. *Science* 235: 1153–1165.
- HOLLAND, S.M., 1993. Sequence stratigraphy of a carbonate-elastic ramp: The Cincinnati Series (Upper Ordovician) in its type area. *Geological Society of America Bulletin* 105: 306–322.
- HOLLAND, S. M., 1998. Sequence stratigraphy of the Cincinnati Series (Upper Ordovician, Cincinnati, Ohio, region). In *Sampling the Layer Cake That Isn't: The Stratigraphy and Paleontology of the Type-Cincinnati*, R.A. Davis & R.J. Cuffey, eds, *Ohio Division of Geological Survey, Guidebook No. 13*, 135–151.
- HUDDLE, J.W., 1967. Silurian conodonts from Kentucky: *U.S. Geological Survey Professional Paper, Geological Survey Research*, 1967, 377 pp.
- HUFF, W.D., MORGAN, D.J. & RUNDLE, C.C., 1997. Silurian K-bentonites of the Welsh borderlands: Geochemistry, mineralogy and K-Ar ages of illitization. *BGS Technical Report WG/96/45 Mineralogy and Petrology Series* 25pp.
- JOHNSON, M.E., 1996. Stable cratonic sequences and a standard for Silurian eustasy. In *Paleozoic Sequence Stratigraphy: Views from the North American Craton*, B.J. Witzke, G.A. Ludvigson & J.E. Day, eds, *Geological Society of America Special Paper* 306, 203–211.
- JOHNSON, M.E., RONG, J.Y. & KERSHAW, S., 1998. Calibrating Silurian eustasy by erosion and burial of coastal paleotopography. In *Silurian Cycles: Linkages of Dynamic Stratigraphy with Atmospheric, Oceanic, and Tectonic Changes*, E. Landing & M.E. Johnson, eds, *New York State Museum Bulletin* 491: 3–13.
- KALJO, D., JOHNSON, M.E., KIPLI, T. & MARTMA, T., 1998. Correlation of carbon isotope events and environmental cyclicity in the East-Baltic Silurian. In *Silurian Cycles: Linkages of Dynamic Stratigraphy with Atmospheric, Oceanic, and Tectonic Changes*, E. Landing & M.E. Johnson, eds, *New York State Museum Bulletin* 491, p. 297–312.
- KIDWELL, S.M., 1991. The stratigraphy of shell concentrations. In *Taphonomy: Releasing the Data Locked in the Fossil Record*, P.A. Allison & D.E.G. Briggs, eds, Plenum, New York, 211–290.
- KLEFFNER, M.A., 1987. Conodonts of the Estill Shale and Bisher Formation (Silurian, southern Ohio): Biostratigraphy and distribution. *Ohio Journal of Science* 87: 78–89.
- KLEFFNER, M.A., 1989. A conodont-based Silurian chronostratigraphy. *Geological Society of America Bulletin* 101: 904–912.
- KLEFFNER, M.A., 1990. Wenlockian (Silurian) conodont biostratigraphy, depositional environments, and depositional history along the eastern flank of the Cincinnati Arch in southern Ohio. *Journal of Paleontology* 64: 319–328.
- KLEFFNER, M.A. & AUSICH, W.I., 1988. Lower and Middle Silurian of the Eastern Flank of the

- Cincinnati Arch and the Appalachian Basin Margin, Ohio. *Field Trip 1, Society of Economic Paleontologists and Mineralogists*, Fifth Midyear Meeting, Columbus, Ohio, 25.
- LEBOLD, J.G., 2000. Quantitative analysis of epizoans on Silurian stromatoporoids within the Brassfield Formation. *Journal of Paleontology* 74: 394–403.
- LIN, B.Y. & BRETT, C.E., 1987. Stratigraphy and disconformable contacts of the Williamson-Willowvale interval: revised correlations of the Late Llandoveryan (Silurian) in New York State. *Northeastern Geology* 10: 241–253.
- LODUCA, S.T. & BRETT, C. E., 1994. Revised stratigraphic and facies relationships of the lower part of the Clinton group (Middle Llandoveryan) of western New York State. In *Studies in Stratigraphy and Paleontology in Honor of Donald W. Fisher*, E. Landing, ed. *New York State Museum Bulletin* 48(1): 161–182.
- LUKASIK, D.M., 1988. Lithostratigraphy of Silurian rocks in southern Ohio and adjacent Kentucky. *Ph.D. dissertation (unpubl.)*, University of Cincinnati, 313 pp.
- MASON, C.E., LIERMAN, R.T., ETTENSOHN, F.R. & PASHIN, J.C., 1992a. Tempestite lithofacies of the Bisher Dolostone and Crab Orchard Shale (Middle Silurian) along Kentucky State highway 546, northeastern Kentucky, Charters section. In *Changing Interpretations of Kentucky Geology: Layer-Cake, Facies, Flexure and Eustasy*, F.R. Ettensohn, ed. *Ohio Division of Geological Survey, Miscellaneous Report* 5, 153–155.
- MASON, C.E., LIERMAN, R.T., ETTENSOHN, F.R., & PASHIN, J.C., 1992b. Sandbelt lithofacies of the Bisher Dolostone, the Crab Orchard Shale, the Upper Olentangy Shale, and the Huron Member of the Ohio Shale in northeastern Kentucky. In *Changing Interpretations of Kentucky Geology: Layer-Cake, Facies, Flexure and Eustasy*, F.R. Ettensohn, ed. *Ohio Division of Geological Survey, Miscellaneous Report* 5, 156–158.
- MCLAUGHLIN, P.I. & BRETT, C.E., 2004. Eustatic and tectonic control on the distribution of marine seismites: examples from the Upper Ordovician of Kentucky, USA. *Sedimentary Geology* 168: 165–192.
- MYERS, K.J. & MILTON, N.J., 1996. Concepts and principles. In *Sequence Stratigraphy*, D. Emery & K.J. Myers, eds, Oxford, Blackwell, 11–44.
- POPE, M.C., READ, J.F., BAMBACH, R. & HOFFMAN, H.J., 1997. Late Middle to Late Ordovician seismites of Kentucky, southwest Ohio and Virginia: Sedimentary recorders of earthquakes in the Appalachian Basin. *Geological Society of America Bulletin* 109: 489–503.
- POTTER, P.E., 1996. Exploring the Geology of the Cincinnati/Northern Kentucky Region. *Kentucky Geological Survey, Special Publication* 22, Series XI, 115 pp.
- POTTER, P.E., AUSICH, W.I., KLEE, J., KRISSEK, L.A., MASON, C. E., SCHUMACHER, G.A., WILSON, T.R. & WRIGHT, E.M., 1991. Geology of the Alexandria-Ashland Highway (Kentucky Highway 546), Maysville to Garrison. *Lcxington, Kentucky Geological Survey Joint Field Conference, Geological Society of Kentucky and Ohio Geological Society*, 64pp.
- PRATT, B.R. & MIAL, A. D., 1993. Anatomy of a bioelastic grainstone megashoal (Middle Silurian, southern Ontario) revealed by ground-penetrating radar. *Geology* 21: 223–226.
- RAY, D.C. & BRETT, C.E., 2001. Sequence and event stratigraphy of the type Wenlock (Silurian): Midland Platform England: Comparison with eastern Laurentia. *Geological Society of America Abstracts with Programs* 33 (1): A-16.
- REXROAD, C.B., 1970. An outline of Silurian conodont zones in the Illinois Basin and the Cincinnati Arch area. In *Correlation of the North American Silurian rocks*, W.B.N. Berry & A.J. Boucot, eds, *Geological Society of America Special Paper* 102, 91–94.
- REXROAD, C.B. & RICKARD, L.V., 1965. Zonal conodonts from the Silurian strata of the Niagara Gorge. *Journal of Paleontology* 39: 1217–1220.
- SCHEIDER, K.A. & AUSICH, W.I., 2002. Paleocology of framebuilders in Early Silurian reefs (Brassfield Formation, Southwestern Ohio): *Palaio* 17: 237–248.
- SCOTSE, C.R., 1990. Atlas of Phanerozoic Plate Tectonic Reconstructions; International Lithophase Program (IUU-IUGS), *Paleomap Project Technical Report* 10-90-1.

- SLOSS, L.L., 1963. Sequences in the eratic interior of North America. *Geological Society of America Bulletin* 74: 93–114.
- SMOSNA, R. & PATCHEN, D., 1978. Silurian evolution of the central Appalachian Basin. *American Association of Petroleum Geologists, Bulletin* 62: 2308–2328.
- STOTT, C.A. & VON BITTER, P. M., 1999. Lithofacies and age variation in the Fossil Hill Formation (Lower Silurian), southern Georgian Bay region, Ontario. *Canadian Journal of Earth Sciences* 36: 1743–1762.
- TELFORD, P.G., 1978. Silurian stratigraphy of the Niagara Escarpment, Niagara Falls to the Bruce Peninsula: *Geological Association of Canada, Toronto '78 Field Trips Guidebook*, p. 28–42.
- VAIL, P.R., MITCHUM, R.M., JR. & THOMPSON, S., III, 1977. Seismic stratigraphy and global changes of sea level, Part 4: Global cycles of relative changes in sea level. In *Seismic Stratigraphy Applications to Hydrocarbon Exploration*, C.E. Payton, ed, *American Association of Petroleum Geologists, Memoir* 26, 83–97.
- VAIL, P.R., AUDEMARD, F., BOWMAN, S.A., EISNER, P.N. & PÉREZ-CRUZ, C., 1991. The stratigraphic signatures of tectonics, eustasy and sedimentation: An overview. In *Cycles and Events in Stratigraphy*, G. Einsele, W. Ricken & A. Seilacher, eds, Springer, New York, 617–659.
- VAN WAGONER, J.C., POSAMENTIER, H.W., MITCHUM, R.M., III, VAIL, P.R., SARG, J.F., LOUTIT, T.S. & HARDENBOL, J., 1988. An overview of the fundamentals of sequence stratigraphy and key definitions. In *Sea-Level Changes: An Integrated Approach*, C.K. Wilgus, B.S. Hastings, C.G. Kendall, H.W. Posamentier, C.A. Ross & J.C. Van Wagoner, eds, *Society of Economic Paleontologists and Mineralogists, Special Publication* 42, 39–45.
- WILGUS, C.K., HASTINGS, B.S., KENDALL, C.G., POSAMENTIER, H.W., ROSS, C.A. & VAN WAGONER, J.C., eds, 1988. *Sea-Level Changes: An Integrated Approach. Society of Economic Paleontologists and Mineralogists, Special Publication* 42. 407 pp.
- WITZKE, B.J., LUDVIGSON, G.A. & DAY, J.E., 1996. Introduction: Paleozoic applications of sequence stratigraphy. In *Paleozoic Sequence Stratigraphy: Views from the North American Craton*, B.J. Witzke, G.A. Ludvigson & J.E. Day, eds, *Geological Society of America Special Paper*, 1–6.

HIGHLY SILICIFIED EARLY DEVONIAN (EMSIAN) BRACHIOPODS FROM THE MURRINDAL LIMESTONE, BUCHAN, EASTERN VICTORIA

JAMES L. VALENTINE

Centre for Ecostratigraphy and Palaeobiology, Department of Earth and Planetary Sciences, Macquarie University, NSW 2109, Australia; fax 61-2-9850-6053; e-mail: james.valentine@students.mq.edu.au.

VALENTINE, J. L., 2005. Silicified Early Devonian (Emsian) brachiopods from the Murrindal Limestone, Buchan, eastern Victoria. *Proceedings of the Royal Society of Victoria* 117(2): 199–264. ISSN 0035-9211.

Silicified Early Devonian (Emsian; *perbourni* Zone) brachiopods from the Murrindal Limestone of eastern Victoria are documented in their entirety for the first time. The fauna consists of 35 species, assigned to 31 genera, and shows closest faunal similarities with the brachiopod faunas of the Murrumbidgee Group of the Taemas-Wee Jasper area of New South Wales. The Murrindal Limestone brachiopod fauna is dominated taxonomically by strophomenids (five genera and five species), orthids (eight genera and eight species) and spiriferids (five genera and six species). However, the atrypids, especially *Atryparia penelopeae* (Chatterton, 1973) (784 ventral valves; 794 dorsal valves; 778 articulated specimens), dominate the fauna numerically. New taxa include the dalmanellid subfamily Bidigitinae subfam. nov. with type species *Bidigitus murrindalensis* gen. et sp. nov.; other new taxa are a dalmanellid, *Biernatium catastium* sp. nov., and a leptaenid, *Notoleptaena adamantea* sp. nov.

Keywords: Buchan, Early Devonian, Murrindal Limestone, rhynchonelliformean brachiopods, Victoria

HIGHLY diverse brachiopod faunas occur in many eastern Australian Devonian carbonate sequences. These include the Broken River Group and Ukalunda Beds of northeast Queensland (Broek 1989; Broek & Talent, 1993); the Garra Limestone (Savage 1969; Lenz & Johnson 1985a, b; Farrell 1992; Brock 2003a, b) and the Murrumbidgee Group (Chatterton 1973) of New South Wales; and the Buchan Group of eastern Victoria (Talent 1956a). However, despite having such prominence, many brachiopod faunas remain undocumented.

The Buchan Group of eastern Victoria (Fig. 1) contains some of the richest Devonian brachiopod faunas in eastern Australia. Despite being known since the 1860s (Selwyn & Ulrich 1867; McCoy 1867), only the brachiopods of the Buchan Caves Limestone have been fully documented (Talent 1956a). Very few taxa have been documented from the Taravale Formation and Murrindal Limestone (Chapman 1913; Gill 1951; Campbell & Talent 1967; Teichert & Talent 1958; Talent et al. 2000, 2001).

GEOLOGY AND STRATIGRAPHY

The Buchan Group, a 1100 m carbonate-mudstone succession, outcrops in a broad north-south synclinal structure in the Buchan-Murrindal area of east-

ern Victoria (Fig. 1) as well as at Bindi, The Basin and numerous other areas where only parts of the lowest unit, the Buchan Caves Limestone have been preserved (see Mawson 1987: figs 1–5). The Buchan Caves Limestone rests disconformably, or with minor unconformity, on the Snowy River Volcanics (Fig. 2) (Teichert & Talent 1958; Mawson 1987; Mawson et al. 1992) and is conformably overlain by the Taravale Formation (Fig. 2), a sequence of mudstones and shales with subordinate limestones tending to be nodular (Teichert & Talent 1958; Mawson 1987) and apparently deposited on a southwards sloping submarine shelf (Talent 1965a, 1969). The group reaches a thickness of around 600 m at the southern end of the Buchan Syncline. At the northern end of the Buchan Syncline, the Taravale Formation occurs as two poorly outcropping tongues of mudstone and calcareous mudstone with occasional beds of limestone and nodular limestone: the Pyramids Mudstone Member (Teichert & Talent 1958) — between the Buchan Caves Limestone and the overlying Murrindal Limestone (Fig. 2) — and an unnamed poorly outcropping tongue, referred to as the Upper Taravale Formation in Fig. 2, overlying the Murrindal Limestone and known primarily from deeply weathered exposures in road cuttings; the stratigraphy and palaeontology of this unnamed member are poorly known. The Pyramids Member

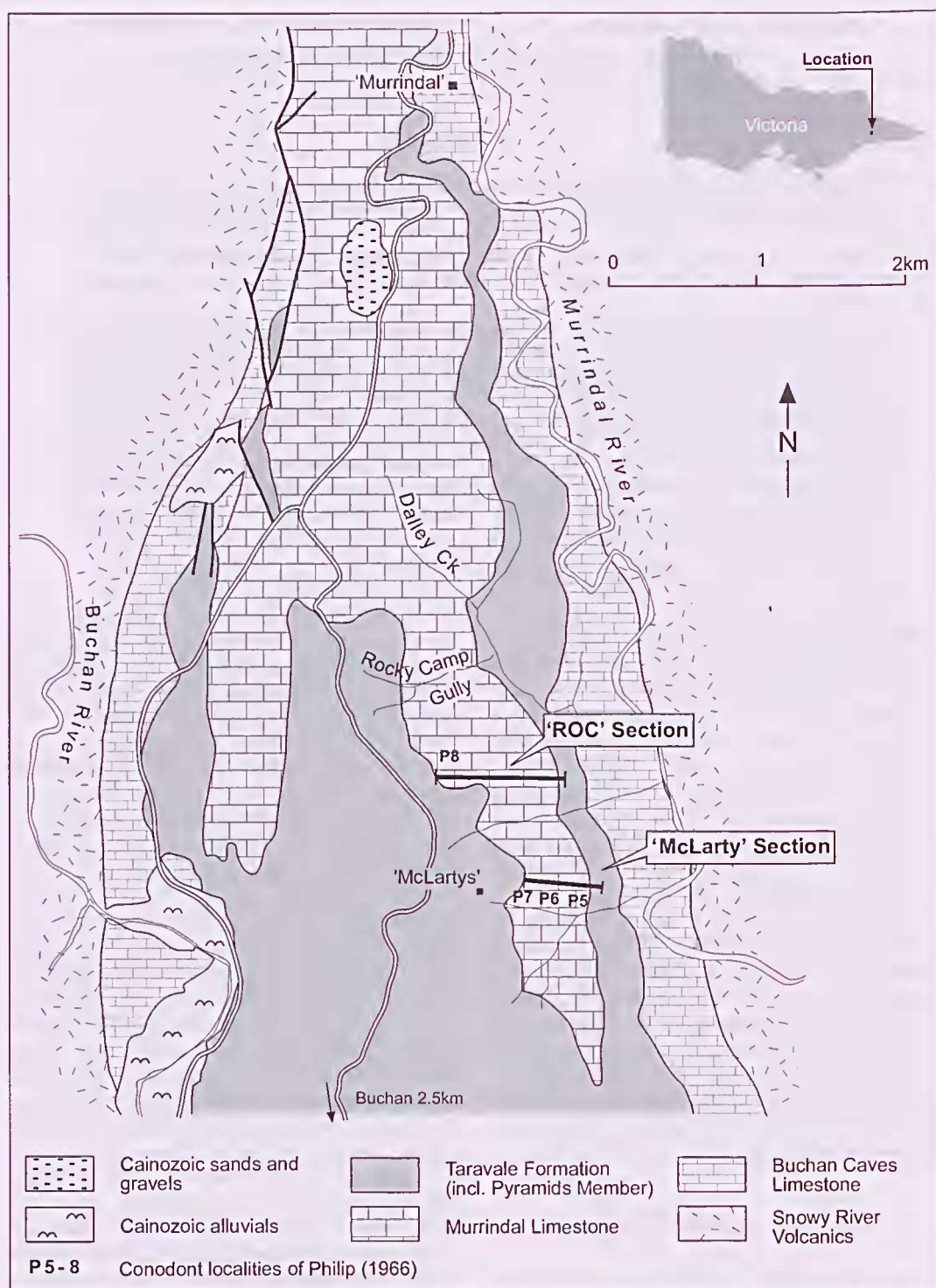


Fig. 1. The Buchan-Murrindal area, eastern Victoria (after Mawson 1987).

is occasionally highly fossiliferous, the proportion of carbonate increasing northwards until a short distance north of Murrindal State School (see Mawson 1987: fig. 1) where it can no longer be differentiated from the overlying and underlying units (Teichert & Talent 1958; Mawson 1987).

The middle part of the Taravale Formation grades laterally into the Murrindal Limestone a few kilometres north of Buchan (Fig. 2). This unit is up to 250 m thick and consists of a broad spectrum of carbonate lithologies including micrites, calcarenites, a few rudites, calcareous mudstones (especially southwards towards Moon's Road), algal mudstones and a prominent algal biostrome outcropping about 75 m above the base of the formation. Based on conodont data, it has been suggested that the Murrindal Limestone accumulated more rapidly than the deeper water nodular limestones, shales and impure limestones of the Taravale Formation (Hyland & Pyemont in Mawson et al. 1988). The wide range of carbonate lithologies accords with a situation in which there was considerable patchiness in carbonate environments (and biofacies), the areas and relationships of these fluctuating through time.

Teichert & Talent (1958) discriminated two members within the Murrindal Limestone (Fig. 2), the well-bedded, typically dark grey, McLarty Mem-

ber representing shallow shelf, but not intertidal carbonate environments, and the less well-bedded, paler grey limestones of the Rocky Camp Member, interpreted as being biohermal in origin (Mawson 1987; Wallace 1987; Holloway 1996). These build-ups are now interpreted as carbonate mud-mounds (Wallace 1987).

PREVIOUS WORK

The presence of limestone outcrops in the Buchan-Murrindal area of eastern Victoria was first mentioned by Selwyn & Ulrich (1867) who believed they may have been Devonian in age, based on McCoy's (1867) identification of *Spirifera laevicosta* (Valenciennes in Lamarek, 1819) (species name misspelled *laevicostata* until Chapman's (1905) review of the species), a Middle Devonian brachiopod occurring in the Eifel Hills of western Germany. McCoy (1876) described in detail the first fossils from the Buchan limestones which included *Favosites goldfussi* d'Orbigny, 1850, *Spirifera laevicosta*, *Chonetes australis* McCoy, 1876, *Phragmoceras subtrigonium* McCoy, 1876, and *Asterolepis ornatus* var. *australis* McCoy, 1876. The first geological survey of the area was undertaken by Howitt (1876: 203), who described the Buchan limestones as being compact and dark blue to almost black limestone deposited some distance from land in seas of moderate depth. Howitt (1876) accepted McCoy's (1867) view that the Buchan limestones were Middle Devonian, an assessment not seriously challenged until the 1960s.

During the 1940s, Teichert undertook the first detailed study of the geological structure and stratigraphy of the Buchan-Murrindal area and is primarily responsible for the stratigraphic nomenclature that came to be applied to what was formerly referred to as the 'Buchan Limestones'. The lowest unit he termed the Cave Limestone (Teichert 1948), subsequently amended to Buchan Caves Limestone to avoid confusion with similarly named units elsewhere in Australia. He initially regarded the overlying limestone-mudstone sequence as consisting of two units, the Lower Murrindal Beds — with the goniatite *Gyroceratites* von Meyer, 1831 and baeitrid *Lobobactrites* Schindewolf, 1932 — and the Upper Murrindal Beds. This nomenclature was used by Hill (1950) when describing corals collected by Teichert and sent to her for identification.

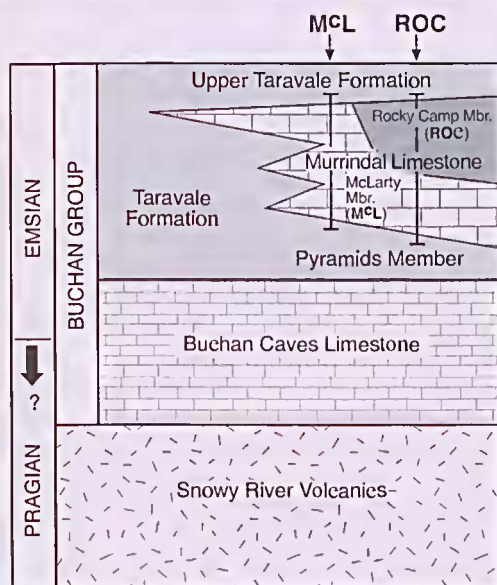


Fig. 2. Stratigraphy of the Buchan district showing the two sections, McL and ROC, through the Murrindal Limestone sampled for brachiopods (not to scale) (after Mawson 1987 and Holloway 1996).

Teichert & Talent (1958) provided a comprehensive account of the geology and stratigraphy of the post-Snowy River Volcanics sequence of the Buchan area and, on the basis of extensive collections, provided the first overview of the abundant and diverse fossil assemblages occurring at many horizons throughout the Buchan Group. Since then, several groups have received additional attention: fish remains (Long 1984, 1986; Burrow & Turner 1998; Basden 1999), conodonts (Mawson 1987; Hyland & Pyemont in Mawson et al. 1988; Pyemont 1990; Mawson et al. 1992), chitinozoans (Winchester-Seeto & Paris 1989; Winchester-Seeto 1996), bivalves (Johnston 1993), stromatoporoids (Webby et al. 1993), trilobites (Holloway 1996), foraminifers (Bell 1996; Bell & Winchester-Seeto 1999), daeryoeonarids (Alberti 1993, 1995) and disarticulated erinoid remains (Stukalina & Talent unpubl. data).

Teichert & Talent (1958) believed the Buchan Group to be early Middle Devonian in age, with the possibility that the Buchan Caves Limestone extended down into the latest part of the Early Devonian. This assessment was based primarily on the presence of the bactritid, *Lobobactrites* and goniatite, *Gyroceratites* (Teichert 1948) from the Taravale Formation, and to a lesser extent on the presence of the trilobites *Harpes* Goldfuss, 1839 and *Scutellum* Pusch, 1833 in the uppermost parts of the Buchan Group. Hill's (1950) opinion, based on tabulate and rugose corals, was in accord with this assignment.

Erben (1960, 1962, 1964, 1965), Chlupáč (1976) and House (1979) reconsidered the identity of the goniatites described by Teichert (1948) and, *inter alia*, proposed several new genera including two from Buchan, *Teicherticeras* Erben, 1960 (an Emsian form) and, subsequently, *Talentoceras* Erben, 1965. This, together with subsequent work on other groups including conodonts (Philip & Pedder 1964; Philip 1966), triggered realization that some, if not all, of the sequence was late Early Devonian (Emsian) in age.

The pioneering conodont work of Philip & Pedder (1964) and Philip (1966) has now been superseded by conodonts from several hundred samples collected from measured stratigraphic sections (often bed-by-bed sampling; present database > 10,000 conodonts, Mawson pers. comm.) through all units of the Buchan Group in the Buchan-Murrindal area and from Bindi, The Basin, Dead Horse Creek, and Boulder Flat, as well as spot sampling in

several other areas (Mawson 1987; Mawson et al. 1988, 1992; Pyemont 1990). This work not only provided tightly constrained ages for all units of the Buchan Group, but conodont data through the goniatite-bearing intervals low in the Taravale Formation suggest these may be the oldest ammonoids in the world (Mawson 1987). Conodont studies of Mawson (1987) and Mawson et al. (1988, 1992) indicated that: the Buchan Caves Limestone belongs to the *dehiscens* Zone (but not latest *dehiscens* Zone), possibly extending down into the *pireneae* Zone (uppermost zone of the Pragian); the Taravale Formation spans the interval from late *dehiscens* Zone through to somewhere in the *serotinus* Zone (late Emsian); the Pyramids Mudstone Member of the Taravale Formation is late *dehiscens* Zone to early *perbonus* Zone; and the Murrindal Limestone extends from early, but not earliest, *perbonus* Zone, through to just before the base of the *inversus* Zone (Mawson et al. 1988: 498–499, table 8).

Bed-by-bed sampling for conodonts along McLarty's Ridge (Fig. 1) undertaken by Mawson, Talent and Hyland embraced the uppermost 62 m of the Pyramids Member of the Taravale Formation, 158 m of the Murrindal Limestone and finished low in the upper, unnamed tongue of Taravale Formation (Fig. 4). Of the 3388 conodonts recovered, *Polygnathus perbonus* (Philip, 1966) and *P. nothoperbonus* Mawson, 1987, were present from the first to the last beds sampled, indicating that the entire section lies within the *perbonus* Zone. A similar exercise conducted along Rocky Camp Ridge (Fig. 1) provided materials for Pyemont's (1990) dissertation. This section commenced 17 m below the base of the Murrindal Limestone and passed through 147.5 m of the Murrindal Limestone and ended very low in the upper tongue of Taravale Formation (Fig. 3). It yielded 1922 conodonts of which *P. perbonus* and *P. nothoperbonus* were dominant; this section too lay entirely within the *perbonus* Zone.

No chitinozoans were obtained from the Murrindal Limestone, but the Taravale Formation — more pelagic as indicated by goniatite and daeryoeonarid faunas — produced 55 species of chitinozoans grouped in seven assemblages (Winchester-Seeto & Paris 1989; Winchester-Seeto 1996), that appear to have only local stratigraphic application. Fifteen of the reported species are new and a further 15 are probably new. Only five species have tentative relationships with Emsian species from Europe (see Winchester-Seeto 1996: 159–160).

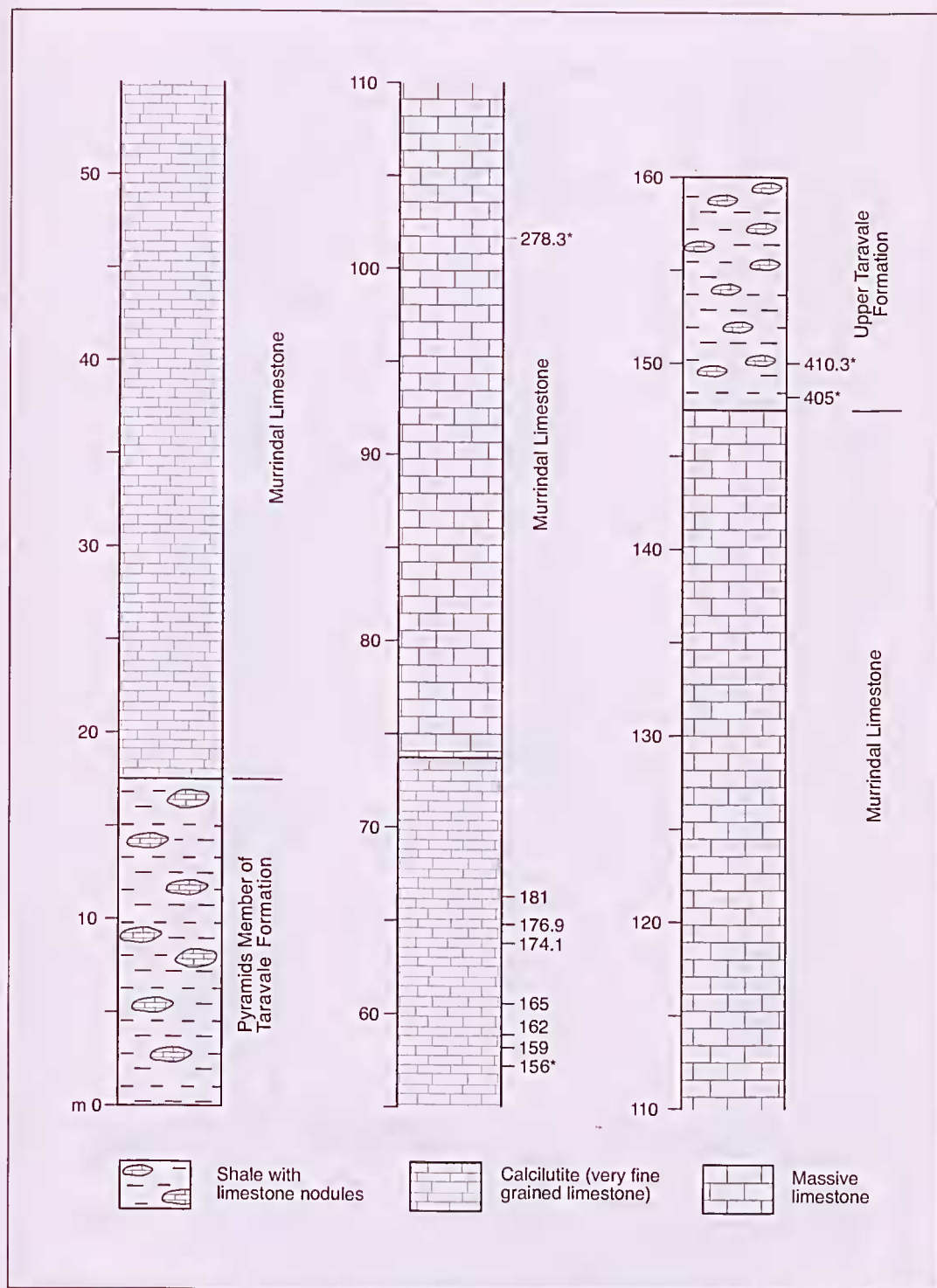


Fig. 3. ROC stratigraphic section (*perbonus* Zone). Numbers on the right hand side of columns indicate silicified horizons from which brachiopods were collected. Those with an asterisk indicate non-silicified horizons.

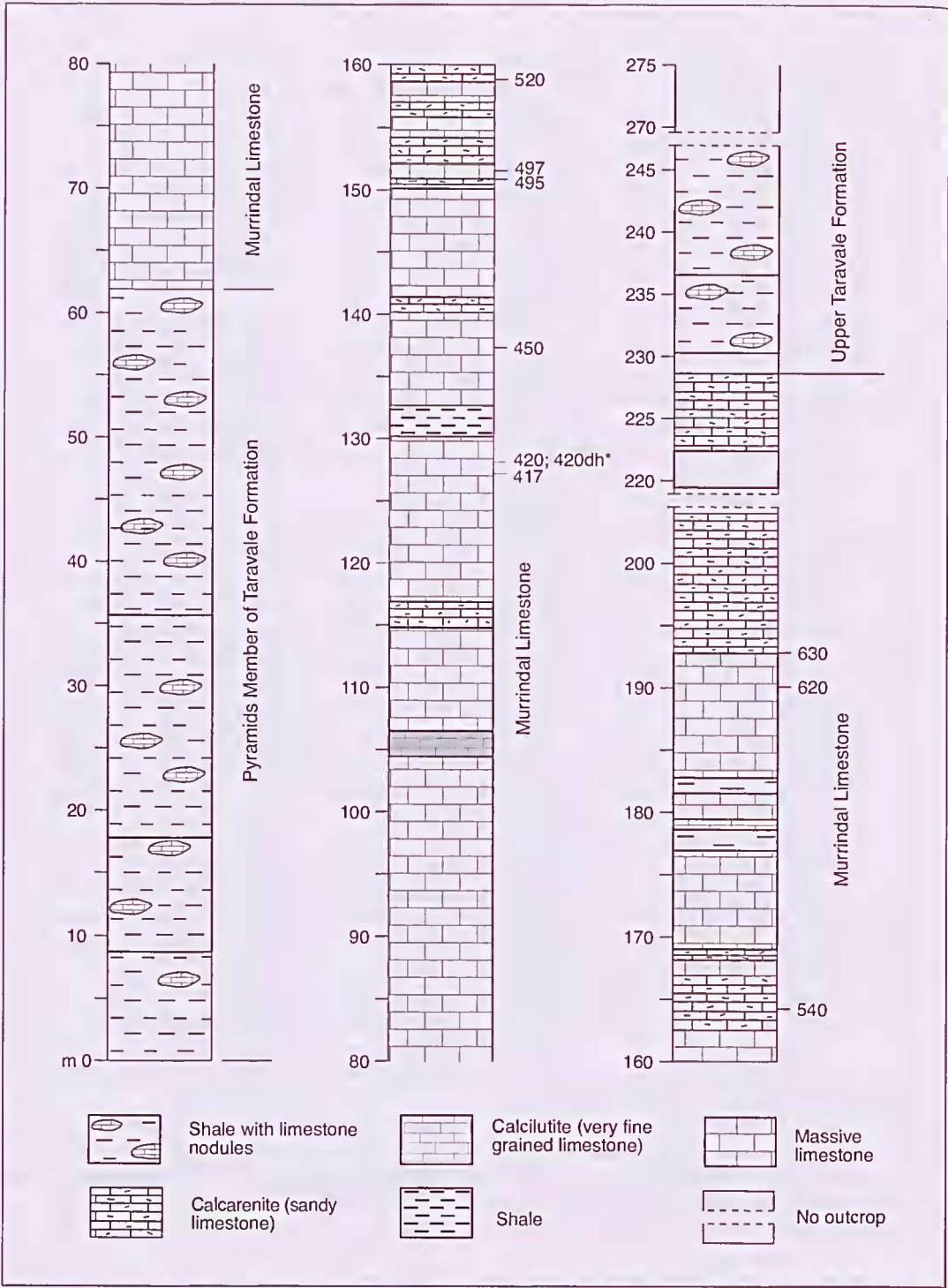


Fig. 4. McL stratigraphic section (*perbonus* Zone) (after Hyland & Pyemont in Mawson et al. 1988). Numbers on the right hand side of columns indicate silicified horizons from which brachiopods were collected. (*dh = down hill).

Brachiopod taxa	Horizons												ROC 410.3		
	ROC 156	ROC 159	ROC 162	ROC 165	ROC 174.1	ROC 176.9	ROC 179	ROC 181	ROC 278.3	ROC 405					
	vv	dv	a	vv	dv	a	vv	dv	a	vv	dv	a	vv	dv	a
<i>Opticoidon areticon</i>															
<i>Opticoidon</i> sp. cf. <i>O. aldrigei</i>															
<i>Coniopsis australis</i>		2	3												
<i>Nonleptana adamantea</i> sp. nov.		11	2	3	34	17	5	4	7	3	1				
<i>Cymatostrophia (Protocymatostrophia) dickinsi</i>		9	2	1	5			7	5	1			16	9	
<i>Maturostrophia</i> sp. cf. <i>M. flabellicauda</i>		2													
<i>Nadustrophia parvirens</i>		19	3	4	1									3	
<i>Mesoleptostrophia (Paraleptostrophia) clarkii</i>		6	4	5	9									5	
<i>Johnsomites australis</i>					1	3	15	7	1			3			
<i>Johnsomites</i> ? sp. cf. <i>J. culleni</i>															
<i>Enschuchertella murphyi</i>							3			1					
<i>Dolerorthis</i> sp.		1			4	1	3								
Hesperorthidae gen. et sp. indet.															
<i>Tyrsella spoleni</i>		88	82	1	71	51	6			35	42	5	8	17	1
<i>Protopia hillae</i>								5						15	21
<i>Reaserella curayi</i>		150	79	46	218	139	87	25	9	17	79	47	4	19	9
<i>Blidgites murrindalensis</i> gen. et sp. nov.		5	4		40	17		3	1	9	2	2	2	28	11
<i>Aulacella philipi</i>		4	3	1	3			1	5	73				13	4
<i>Engelstenoisochia linki</i>														1	
<i>Pugnax</i> ? sp. cf. <i>P. uepiki</i>		2	37					9	4	10	6		3		
<i>Spinella buchanensis</i>		2	6		3								28	1	10
<i>Spinella buchanensis</i> sp. nov.		1			4										
<i>Howellia (Howellia) testilis</i>													2		
<i>Howellia howitti</i>		2	1	1	2	3		1	5	2	6				
<i>Cyrtina wellingtonensis</i>															
<i>Atrypa penelopeae</i>		28	18	57	1	1	21	19	9	32			1		2
<i>Atrypa (Atrypa) erectirostris</i>					506	520	458	25	21	91	7	1	25	27	12
<i>Buchanadyris westoni</i>					41	18	72	3	2	19			5	5	1
<i>Micidus shandhykii</i>		20	28	6	105	109	9	10	3	6	3		15	18	1
<i>Micidus</i> ? sp. cf. <i>M. glaber</i>													6	5	11
														9	25
															2

Table 1. Stratigraphic distribution of brachiopods collected from the ROC section (*perbonus* Zone) through the Murrindal Limestone, Buchan, Victoria. Abbreviations: vv = ventral valve; dv = dorsal valve; a = articulated specimen.

Brachiopod taxa	Horizons		MFL 417		MFL 420		MFL 420dh		MFL 450		MFL 495		MFL 497		MFL 520		MFL 540		MFL 620	
	vv	dv	a		vv	dv	a		vv	dv	a		vv	dv	a		vv	dv	a	
<i>Crinops australis</i>	5	2	1												1					
<i>Notoleptacna adamantina</i> sp. nov.	3	1									1									
<i>Cynostrophia (Protocynostrophia) dickinsi</i>	2		1					12	7	1					6	2	3			
<i>Malvostrophia</i> sp. cf. <i>M. fabellicauda</i>															1					
<i>Nadiastrophia palmieri</i>								1		3					2					
<i>Mesoleptostrophia (Puraleptostrophia) clarkiei</i>	3					1		4			1				2					
<i>Johnsonites australis</i>		2													1					
<i>Eoschuchertella murphyi</i>	7	1	2			1									2					
<i>Dolerorthis</i> sp.	19	23	4												1					
<i>Tyrsocella spidanti</i>					5	7		17							3	9				
<i>Prokopia hillae</i>	1	1						63	21	11			1		4	1				
<i>Resserella curryi</i>	60	24	10		4	4	1	16	23	6					13	20	1			
<i>Bigditus murrindalensis</i> gen. et sp. nov.	7	4	1					7	1	1					9	24	2			
<i>Biernatium calatum</i> sp. nov.															1					
<i>Aulacella philipi</i>	5	10	1		27	40		4	7											
<i>Eoglossinotocchia lenti</i>		2													1					
<i>Pugnax</i> sp.	4	2	137			2									3					
<i>Spinella buchaneensis</i>	5	3			2															
<i>Spinella yassensis</i>	2																			
<i>Ambocella</i> sp. aff. <i>A. runnegari</i>	3	3																		
<i>Delthyris</i> ? sp.																				
<i>Howellella (Howellella) rextilis</i>	31	19	4		5	2	3	4		6			2	1	3	11	9	1		
<i>Howittia howittii</i>		3														16	10	1		
<i>Cyrtina wellingtonensis</i>	12	4	16		2	1		49	38	83										
<i>Atryparia penelopeae</i>	105	115	109		1						1		3		2	2	1	2	3	1
<i>Variatrypa (Variatrypa) erectirostris</i>	8	1	8																	
<i>Coelospira luyi</i>																				
<i>Buchanathyrus westoni</i>	41	36	1		3	2		1	3				1	5	12		1	2		
<i>Nucleospira</i> sp.											2									
<i>Micidius shandkyddi</i>	1	11			1	1														
<i>Micidius</i> ? <i>glober</i>		11																		

Table 2. Stratigraphic distribution of brachiopods collected from the McL. section (*perbonus* Zone) through the Murrindal Limestone, Buchan, Victoria. Abbreviations as for Table 1.

SYSTEMATIC PALEONTOLOGY

Brachiopods for this project were collected from sili-cified horizons along the Rocky Camp Ridge (ROC) and McLarty Ridge (McL) sections through the Murrindal Limestone (Figs 1, 3, 4, Tables 1, 2). All type and figured material is lodged in the palaeontological collections of the Australian Museum (AM F).

Phylum BRACHIOPODA Duméril, 1806

Remarks. Unless otherwise mentioned, the higher level classification used herein follows that of Kaesler (2000, 2002).

Subphylum LINGULIFORMEA Williams, Carlson, Brunton, Holmer & Popov, 1996
Class LINGULATA Gorjansky & Popov, 1985
Order ACROTRETIDA Kuhn, 1989
Superfamily ACROTRETOIDEA Schuchert, 1893
Family BIERNATIDAE Holmer, 1989

Opsiconidion Ludvigsen, 1974

Type species. By original designation of Ludvigsen (1974: 143); *Opsiconidion arcticon* Ludvigsen, 1974; early Emsian of the Michelle Formation, Yukon Territory, Canada.

Remarks. *Opsiconidion* is one of only six known genera of post-Ordovician acrotretid brachiopods (Krause & Rowell 1975; Biernat & Bednarczyk 1990; Brock et al. 1995; Mergl 2001) and ranges from Ordovician (Ashgill) to Middle or ?Upper Devonian (Holmer & Popov 2000). Brock et al. (1995) documented four species of *Opsiconidion* from New South Wales and Victoria ranging from the Lochkovian (*pesavis* Zone) to Emsian (*dehiscens* Zone). Brock et al. (1995) also reported the presence of three poorly preserved dorsal valves from the Middle Devonian Yarranie Formation of New South Wales. These were questionably referred to *O. minor* Popov, 1981a, possibly extending the stratigraphic range of this genus in Australia to the Givetian (*varcus* Zone). However, additional material is required to confirm this.

Opsiconidion arcticon Ludvigsen, 1974
Fig. 5A-C

Opsiconidion arcticon Ludvigsen 1974: 145, fig. 4, 1-3; fig. 5, 1-8.-von Bitter & Ludvigsen 1979: 707, pl. 90, figs 1-12; pl. 91, figs

1-12.-Brock, Engelbretsen & Dean-Jones 1995: 111, figs 4A-F.-Brock 2003a: 104, pl. 1, figs 8-13, 15-16.

Material. Figured material: AM F117236 (Fig. 5A, B): ventral valve from sample ROC 156; AM F117237 (Fig. 5C): dorsal valve from sample ROC 156. Unfigured material: one dorsal valve.

Description. See Ludvigsen (1974: 145) and von Bitter & Ludvigsen (1979: 707).

Remarks. *Opsiconidion arcticon* was first documented in Australia by Brock et al. (1995: 111) from various Early Devonian localities in New South Wales and Victoria. The presence of *O. arcticon* in the ROC section of the Murrindal Limestone extends its stratigraphic range in Australia from the Pragian (*kindlei* Zone) into the Emsian (*perbonus* Zone). *Opsiconidion arcticon* has otherwise been recovered from the Lochkovian Garra Limestone at Eurimbla (Brock 2003a), the Emsian Michelle Formation in the Yukon Territory of Canada (Ludvigsen 1974) and the Lower and Middle Devonian Bois Blanc, Onondaga and Dundee Formations of Ontario (von Bitter & Ludvigsen 1979).

As outlined by Brock et al. (1995) and Brock (2003a), the diagnostic features of *Opsiconidion* are the morphology of the dorsal valve pseudointerarea and to a lesser extent, the outline of the dorsal valve. The dorsal valve pseudointerarea of *O. arcticon* is crescentic and lacks a median plate, whereas the dorsal valve outline is almost circular (Fig. 5C). *Opsiconidion* sp. cf. *O. aldridgei* (Cocks, 1979), from various Early Devonian localities in New South Wales and Victoria (see Brock et al. 1995: 111 and Brock 2003a: 104), has a less well rounded dorsal valve and a dorsal valve pseudointerarea with a straight anterior margin and a well defined median plate. *Opsiconidion minor* from the Emsian of Valnov Island, Novaja Zemlja (Popov 1981a) and various localities in New South Wales and Victoria (see Brock et al. 1995: 113), differs in having an acutely subtriangular dorsal valve pseudointerarea, a well-defined median plate and propareas and a less well-rounded dorsal valve. *Opsiconidion robustum* Brock, Engelbretsen & Dean-Jones, 1995 from the Early Devonian of New South Wales (see Brock et al. 1995: 114) is distinguished by its external ornament of well defined concentric fila, squat, conical and robust ventral valve, straight dorsal valve pseudointerarea and sub-polygonal dorsal valve outline.

Opsiconidion sp. cf. *O. aldridgei* (Cocks, 1979)
Fig. 5D, E

?*Caenotreta aldridgei* sp. nov. Cocks 1979: 96, pl. 13,
figs 1–7; pl. 14, figs 1–4.

?*Caenotreta celloni* sp. nov. Cocks 1979: 98, pl. 14,
figs 6–8.

Opsiconidion sp. cf. *O. aldridgei*-Broek, Engelbretsen & Dean-Jones 1995: 111, fig. 5A-K.-
Broek 2003a: 104, pl. 1, fig. 14.

Material. Figured material: AM F117238 (Fig. 5D):
dorsal valve from ROC 410.3; AM F117239 (Fig.
5E): dorsal valve from ROC 410.3.

Description. See Cocks (1979: 96).

Remarks. The dorsal valve pseudointerarea of *O. aldridgei* is short and wide, with a straight anterior edge and a well-defined median plate. The dorsal valve is subcircular in outline (Cocks 1979; Brock et al. 1995). Brock et al. (1995) and Brock (2003a) differentiated between *O. sp. cf. O. aldridgei* from various Early Devonian localities in New South Wales and Victoria (see Brock et al. 1995: 111 and Brock 2003a: 104) and *O. aldridgei* from the Llandovery of the Welsh Borderlands (Cocks 1979), the Llandovery to Wenlock of Saaremaa, Estonia (Popov 1981b) and the Boree Creek Formation of central-western New South Wales (Valentine et al. 2003), because the median plate of the Early Devonian specimens is less distinct. The Murrindal specimens are most similar to those described by Brock et al. (1995) and Brock (2003a). This extends the stratigraphic range of the *O. sp. cf. O. aldridgei* from the Pragian (*kindlei* Zone) to the Emsian (*perbonus* Zone).

Opsiconidion praecursor Popov, Nölvak & Holmer, 1994, from the Upper Ordovician Harju Series of southern Estonia, is very similar to *O. aldridgei*. The dorsal valve outline of both species is subcircular and both have an anacline pseudointerarea with a straight anterior margin. *Opsiconidion praecursor* differs in being smaller, having a relatively smaller dorsal valve pseudointerarea and pos-

sessing large larval pits surrounded by clusters of smaller ones (Popov et al. 1994).

Opsiconidion arcticon, from various Early Devonian localities in New South Wales and Victoria (see Brock et al. 1995: 111 and Brock 2003a: 104), the Emsian Michelle Formation in the Yukon Territory of Canada (Ludvigsen 1974), and the Lower and Middle Devonian Bois Blanc, Onondaga and Dundee Formations of Ontario (von Bitter & Ludvigsen 1979), possesses a similar ventral valve to *O. sp. cf. O. aldridgei*, but the latter has a slightly flattened pseudointerarea. The dorsal valve of *O. arcticon* has a more circular outline and crescentic pseudointerarea. *Opsiconidion minor*, from the Emsian of Valnov Island, Novaja Zemlja (Popov 1981a) and also recovered by Brock et al. (1995: 113) from various Early Devonian localities in New South Wales and Victoria, differs in having an acutely subtriangular pseudointerarea and a well-defined median plate. *Opsiconidion robustum* from the Early Devonian of New South Wales and Victoria (Brock et al. 1995: 114) is distinguishable by its external ornament of well-defined concentric fila, its squat, conical and robust ventral valve and sub-polygonal dorsal valve outline.

Subphylum CRANIIFORMEA Popov, Bassett,
Holmer & Laurie, 1993

Class CRANIATA Williams, Carlson, Brunton,
Holmer & Popov, 1996

Order CRANIOPSIDA Gorjansky & Popov, 1985

Superfamily CRANIOPSOIDEA Williams, 1963

Family CRANIOPSIDAE Williams, 1963

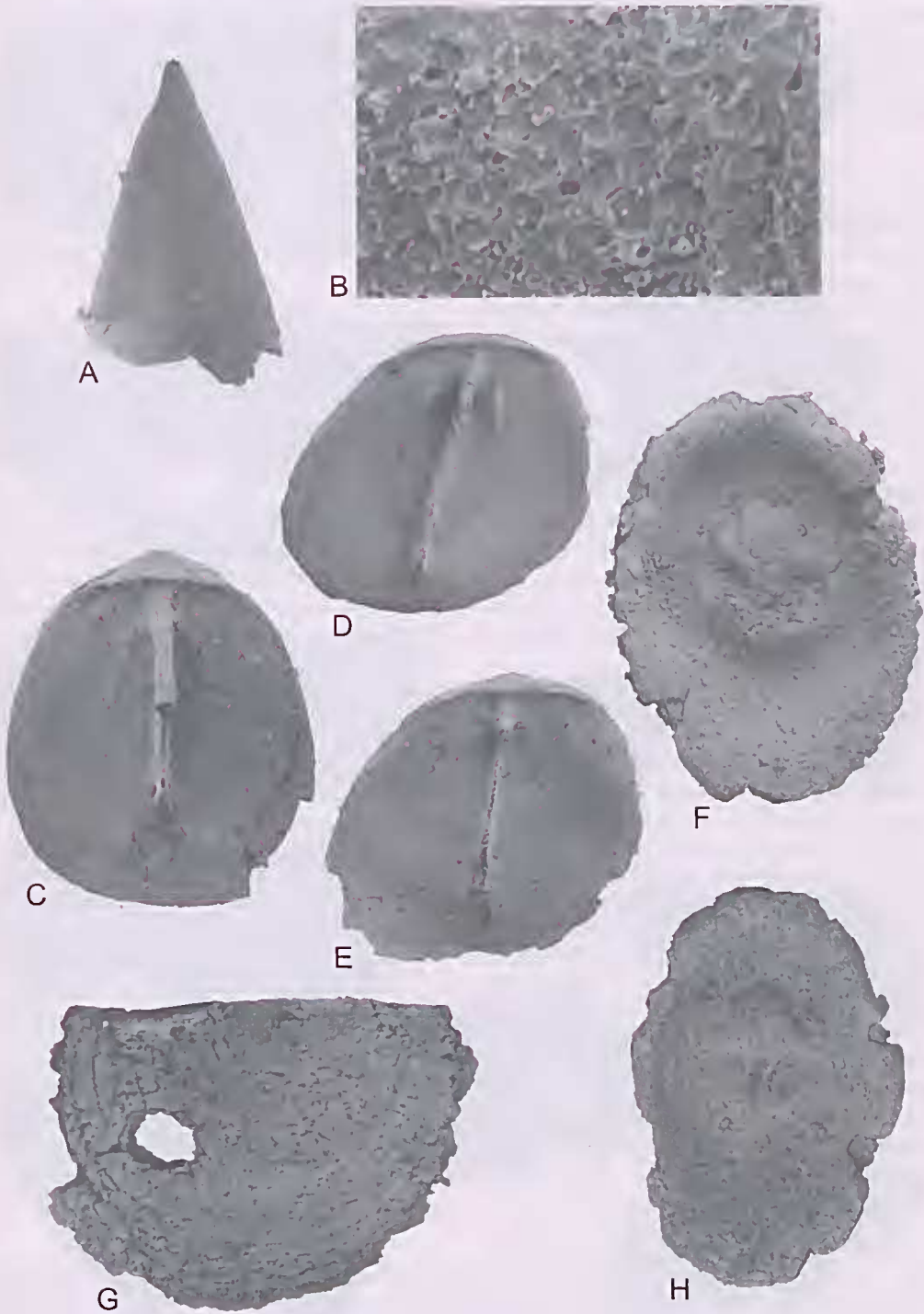
Craniops Hall, 1859a

Type species. By original designation of Hall (1859a: 84); *Orbicula? squamiformis* Hall, 1843; Lochkovian of the Helderberg Group, New York, America.

Craniops australis Chatterton, 1973
Fig. 5F-H

Craniops australis sp. nov. Chatterton 1973: 17, pl. 1,
figs 1–7; pl. 5, figs 26–30.

Fig. 5. A–C, *Opsiconidion arcticon* Ludvigsen, 1974. A, B, ventral valve lateral view, x 120, close up of ventral valve larval shell pitting x 2670, ROC 156, AM F117236. C, dorsal valve interior, ROC 156, AM F117237, x 94. D, E, *Opsiconidion* sp. cf. *O. aldridgei* (Cocks, 1979). D, dorsal valve interior in lateral oblique view, ROC 410.3, AM F117238, x 69. E, dorsal valve interior in lateral oblique view, ROC 410.3, AM F117239, x 69. F–H, *Craniops australis* Chatterton, 1973. F, ventral valve interior, ROC 176.9, AM F117240, x 37. G, ventral valve exterior, ROC 176.9, AM F117241, x 33. H, dorsal valve interior, ROC 159, AM F117242, x 37.



Material. Figured material: AM F117240 (Fig. 5F): ventral valve from ROC 176.9; AM F117241 (Fig. 5G): ventral valve from ROC 176.9; AM F117242 (Fig. 5H) dorsal valve from ROC 159. Unfigured material: ten ventral valves, seven dorsal valves and two complete specimens.

Description. See Chatterton (1973: 17).

Remarks. *Craniops australis* from the Emsian 'Receptaculites' and Warroo Limestone Members of the Taemas Limestone at Taemas and the Murrindal Limestone at Buchan, differs in several ways from the *C. squamiformis*. *Craniops squamiformis* has a thinner shell, a more subquadrate outline and finer, more numerous and closely spaced growth lines. The apex of *C. australis* is located closer to the posterior margin than the apex of *C. squamiformis*. Hall (1859a) also mentioned the presence of fine radiating striae crossing the lamellae in well-preserved specimens of *C. squamiformis*, as does Chatterton (1973) for some specimens of *C. australis*. However, Chatterton's (1973: pl. 1, figs 1–7; pl. 5, figs 26–30) figured material show no trace of radial striae, nor do any of the Murrindal specimens (Fig. 5G).

Craniops australis is the only definite occurrence of this genus in Australia. A questionable occurrence was reported by Strusz (1982) from the Wenlock Walker Volcanics near Canberra. Though externally resembling *Craniops*, this assignment is tentative owing to a lack of material showing sufficient detail of internal features and doubts over the presence of an attachment scar (Strusz 1982).

Craniops australis appears most closely related to *Craniops* sp. 1 of Perry (1984) from the late Emsian of the Delorme Formation of western Canada. Although both are similar in terms of outline, ornament and muscle scar impressions, the Delorme specimens possess a much more prominent attachment scar. *Craniops patina* (Hall & Clarke, 1893) from late Emsian beds of the Bois Blanc Formation of Ontario is externally similar to *C. australis*; the two species also possess similar muscle scar impressions. They differ most notably in that the dorsal

valve of *C. patina* possesses a median ridge located between the anterior adductor scars.

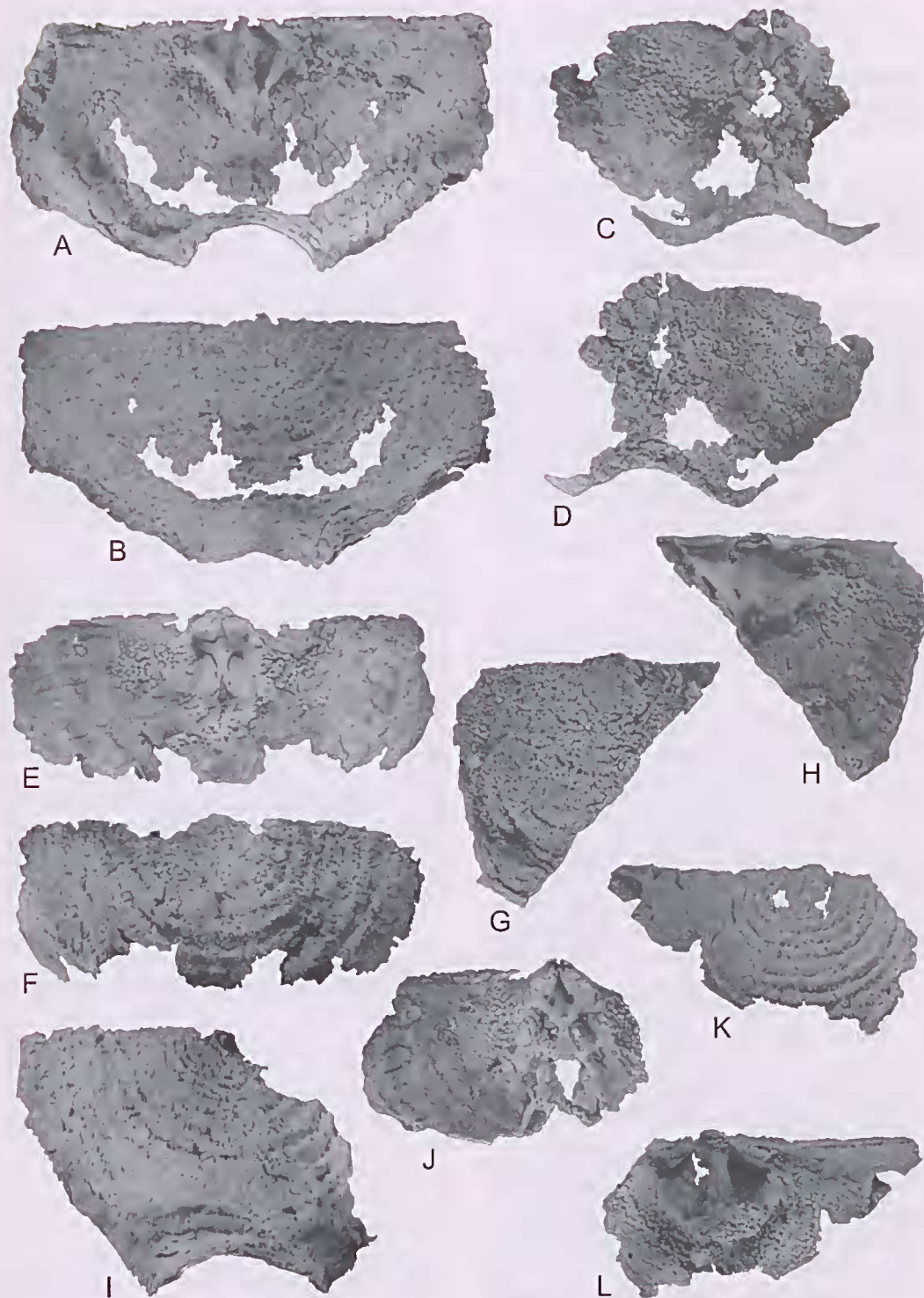
Subphylum RHYNCHONELLIFORMEA Williams, Carlson, Brunton, Holmer & Popov, 1996
Class STROPHOMENATA Williams, Carlson, Brunton, Holmer & Popov, 1996
Order STROPHOMENIDA Öpik, 1934
Superfamily STROPHOMENOIDEA King, 1846
Family RAFINESQUINIDAE Schuchert, 1913
Subfamily LEPTAENINAE Hall & Clarke, 1894

Notoleptaena Gill, 1951

Type species. By original designation of Gill (1951: 191); *Notoleptaena linguifera* Gill, 1951; Lochkovian-Pragian, Stoddart Member of the Mount Ida Formation, Heathcote-Redcastle district, Victoria, Australia.

Remarks. Apart from one species left under open nomenclature by Pajchlowa (1957) from the Devonian deposits of the eastern part of the Bodzentyn synclinal outcrops in the region of Grzegorzowice and Skaly, Poland, all occurrences of *Notoleptaena* are restricted to Australia. However, as Pajchlowa (1957) neither figured nor described this specimen, no comparisons are possible. The type species has been recovered from the Lochkovian-Pragian of the Stoddart Member of the Mount Ida Formation (Mawson & Talent 2000), and *N. cf. linguifera* occurs in the Pragian Garra Limestone at Wellington (Lenz & Johnson 1985a), but has since been referred to *Glossoleptaena* Havlíček, 1956 by Brock (2003a). *Notoleptaena otoptera* Gill, 1951 is widely distributed, having been recovered from the Lochkovian-Pragian Mount Ida Formation unit 3 (*Pleurodictyum* Beds), the Lochkovian Humevale Formation and the latest Lochkovian Boola Siltstone of Victoria. *Notoleptaena* aff. *otoptera* occurs in the ?early Lochkovian Maradana Shale of New South Wales (Savage 1974). A third species, *N. undulifera* Talent, 1956b occurs in the Pragian Tabberabbera Formation of Victoria. *Notoleptaena adamantea* extends the stratigraphic range of this genus into the Emsian (*perbomus* Zone).

Fig. 6. A–L *Notoleptaena adamantea* sp. nov. All specimens x 2. A, B, holotype, ventral valve interior and exterior, ROC 181, AM F117243. C, D, dorsal valve interior and exterior, ROC 159, AM F117244. E, F, dorsal valve interior and exterior, ROC 181, AM F117245. G, H, ventral valve exterior and interior, ROC 159, AM F117246. I, dorsal view of articulated specimen, ROC 181, AM F117247. J, dorsal valve interior, ROC 165, AM F117248. K, L, ventral valve exterior and interior, ROC 165, AM F117249.



***Notoleptaena adamantea* sp. nov.**

Fig. 6A-L

Etymology. L., *adamantea*, like a diamond; in reference to the diamond shaped muscle field of the ventral valve.

Diagnosis. *Notoleptaena* with diamond-shaped ventral valve muscle field, surrounded by strong muscle bounding ridges. Hinge line faintly denticulate for most of length. Delthyrium trapezoidal.

Type material. Holotype: AM F117243 (Fig. 6A, B): ventral valve from ROC 181. Figured paratypes: AM F117244 (Fig. 6C, D): dorsal valve from ROC 159; AM F117245 (Fig. 6E, F): dorsal valve from ROC 181; AM F117246 (Fig. 6G, H): ventral valve from ROC 159; AM F117247 (Fig. 6I): articulated specimen from ROC 181; AM F 117248 (Fig. 6J): dorsal valve from ROC 165; AM F117249 (Fig. 6K, L): ventral valve from ROC 165. Unfigured paratypes: 75 ventral valves, 28 dorsal valves and 17 articulated specimens.

Type locality and horizon. ROC section (sample ROC 181), Emsian (*perbonus* Zone) Murrindal Limestone, Buchan Group, Buchan, Victoria, Australia.

Description. Semicircular outline, maximum width at, or slightly forward of, hinge line. Up to twice as wide as long. Cardinal extremities variably alate. Visceral region of ventral valve convex; medial region slightly concave. Raised lateral margins, increasing in height anteriorly until reaching strongly dorsally deflected tongue. Visceral and medial regions of dorsal valve planoconvex, valve margins concave. Ornament consisting of weakly to strongly developed and irregularly spaced concentric rugae, 0.7 mm up to 2.8 mm (averaging 1.1 mm) apart. No micro-ornament observed.

Ventral valve interarea steeply apsaeline. Delthyrium trapezoidally shaped. Pseudodeltidium absent. Dorsal valve interarea small, anaeline and triangular. Notothyrium narrowly triangular, with small, fragile chilidium.

Ventral valve interior with well developed, elongately oval and crenulate teeth lying subparallel to hinge line. A broad median ridge begins one quarter to halfway across muscle field, rapidly increasing in height, and slightly in width, anteriorly. Muscle field diamond shaped and strongly excavated. Diductor sears triangular and separated by median ridge. Ad-

ductor sears long, narrow, and located on median ridge. Adductor sears may be divided anteriorly by a low, narrow ridge (0.2 mm wide), located on surface of median ridge. Muscle field bounded laterally and anteriorly by strong muscle bounding ridges that begin slightly forward of teeth. Initially divergent, muscle bounding ridges quickly and sharply turn inwards, rapidly gaining height. Height decreases towards median ridge, but increases again upon joining with median ridge. A rounded peak may be formed where muscle-bounding ridges meet. A sub-peripheral ridge extends around valve edge, joining with dorsally directed tongue anteriorly. Hinge line faintly denticulate for most of length. Inner surface pseudopunctate, especially adjacent to muscle bounding ridges. Faint impressions of external rugae may also be visible.

Dorsal valve interior with erect and strongly bilobed cardinal process. Each lobe of cardinal process oval in cross-section and in some specimens with faint striations along their elongately flattened posterior edge. Sockets shallow, triangular impressions lying adjacent to cardinal process. Subtriangular median ridge short and low, extending forward from cardinal process, rapidly narrowing anteriorly; anterior point of median ridge extended in some specimens and in one bifurcates anteriorly. Adductor sears subcircular, deeply impressed, and separated by median ridge. Two low, broad and gently arcuate anteridia diverge forward from medial portion of cardinal process at 100° and extend anteriorly slightly further than median ridge before fading out. Hinge line faintly denticulate. Inner surface coarsely pseudopunctate, especially adjacent to and on anteridia. Traces of rugae visible internally around valve edges.

Ventral valves		Dorsal valves	
width (mm)	length (mm)	width (mm)	length (mm)
42*		38*	
42*		32*	18
38*	15		14.5
38*		29*	
36*		22*	
34*	16	22*	
32*	21		
31.5	16		
31	12		
28*	17		
25*			

Table 3. Dimensions for *Notoleptaena adamantea* sp. nov. * Indicates dimensions estimated due to incomplete nature of recovered specimens.

Measurements. Dimensions are given in Table 3. Ventral valves average 34.3 mm in width and 16.2 mm in length. Dorsal valves average 28.6 mm in width and 16.3 mm in length.

Remarks. The specimens from the Murrindal Limestone conform to the diagnosis provided by Gill (1951) and Cocks & Rong (2000) for *Notoleptaena*. Generically diagnostic features include a dorsally directed tongue, the muscle field of the ventral being bounded laterally and anteriorly by strong muscle bounding ridges, a subperipheral ridge in the ventral valve, the presence of concentric rugae and a small dorsal valve muscle field. However, unlike previously described species of *Notoleptaena*, this species differs in having irregularly spaced concentric rugae (Fig. 6B, F, G, I, K), a diamond shaped muscle field in the ventral valve muscle field with triangular shaped diductor scars and a faintly denticulate hinge line (Fig. 6A, H, J, L).

Notoleptaena adamantea is further distinguishable from *N. linguifera* and *N. undulifera* by lacking any trace of radial costellae (Fig. 6B, F, G, I, K) or a pseudodeltidium (Fig. 6A, H, L), which may also be lacking in *N. otophera*. *Notoleptaena linguifera* differs further in possessing more strongly developed rugae. *Notoleptaena adamantea*, unlike *N. undulifera* and *N. cf. linguifera*, also possesses well-developed teeth (Fig. 6A, H, L). Whereas *N. linguifera* also possesses well-developed teeth, they lack the crenulations present on the teeth of *N. adamantea* (Fig. 6A, H, L). Dorsal valve interiors are known only for *N. undulifera*, *N. linguifera* and *N. cf. linguifera*; these species and *N. adamantea* all possess a similar cardinal process, but the subtriangular median ridge of *N. adamantea* distinguishes it from the other three taxa (Fig. 6C, E, J).

An unnamed species of *Notoleptaena* from the Lochkovian Bell Shale of the Eldon Group of Tasmania was described by Gill (1950: 253) as being comparable with neither *N. linguifera* nor *N. otophera*. From the little information provided by Gill (1950), it is only possible to differentiate between the Bell Shale specimens and those from the Murrindal Limestone on the basis of their cardinal extremities. The specimens from the Eldon Group possess non-alate cardinal extremities, whereas those of *N. adamantea* are variably alate (Fig. 6A, E, G, I, K). A second unnamed species of *Notoleptaena*, described by Talent (1965b) from the Stoddart Member of the Mount Ida Formation of Victoria, was referred to *N. otophera* by Talent et al. (2001).

Family DOUVILLINIDAE Caster, 1939
Subfamily PROTODOUVILLININAE Harper & Boucot, 1978b

Cymostrophia (Protocymostrophia) Harper & Boucot, 1978b

Type species. By original designation of Caster (1939: 148); *Leptaena stephani* Barrande, 1848; Lochkovian Kotýs Limestone, Svätý Jan pod Skalou, Czech Republic.

Remarks. *Protocymostrophia* was erected by Harper & Boucot (1978b) as a subgenus of *Mesodouvillina* for mesodouvillinids that are moderately to strongly concavo-convex and possess an ornament similar to *Cymostrophia*, features lacking in the other subgenera, *M. (Mesodouviella)* and *M. (Mesodouvillina)*. Whereas Harper & Boucot (1978b) recognised many similarities between *M. (Protocymostrophia)* and *M. (Mesodouvillina)*, they also noted a number of similarities with *Cymostrophia*, including ornament and well-developed brachial plates. According to Harper & Boucot (1978b) these commonalities rarely occur in other mesodouvillinids and Rong & Cocks (1994) stated that such characteristics are important for differentiating strophomenid genera. This no doubt led Rong & Cocks (1994) and Cocks & Rong (2000) to reclassify *M. (Protocymostrophia)* as a subgenus of *Cymostrophia*.

According to Cocks & Rong (2000), *C. (Protocymostrophia)* is distinguishable from *C. (Cymostrophia)* by its suboval outline, gently concavo-convex profile and weakly developed interrupted rugae. *Cymostrophia (Cymostrophia)* possesses a more transverse outline, a strongly convex profile and strongly developed interrupted rugae.

Cymostrophia (Protocymostrophia) dickinsi
(Chatterton, 1973)
Fig. 7A-E

Cymostrophia dickinsi sp. nov. Chatterton 1973: 37, pl. 5, figs 31–33; pl. 6, figs 1–9; pl. 7, figs 1–12; pl. 13, figs 1–5.

Cymostrophia multicoscella sp. nov. Chatterton 1973: 42, pl. 6, figs 10–16.

?*Mesodouvillina (Protocymostrophia) cf. dickinsi*-Brock & Talent 1993: 235; fig. 11A, B.

Material. Figured material: AM F117250 (Fig. 7A, B); articulated specimen from McL 417; AM

F117251 (Fig. 7C): ventral valve from ROC 159; AM F117252 (Fig. 7D): ventral valve from ROC 162; AM F117253 (Fig. 7E): dorsal valve fragment from ROC 159. Unfigured material: 42 ventral valves, 17 dorsal valves and 13 articulated specimens.

Description. See Chatterton (1973: 42).

Remarks. Chatterton (1973) assigned two new species, *C. dickinsi* and *C. multicostralla*, from the Emsian 'Receptaculites' Limestone Member to *Cynostrophia*, as they agreed the description provided by Caster (1939: 148) for *Cynostrophia*. Chatterton (1973) noted, however, these species differed from Havlíček's (1967: 126) diagnosis for *Cynostrophia* in possessing a convex, rather than a flat, pseudodeltidium, a feature Chatterton (1973) did not regard as generically significant. Harper & Boucot (1978b) subsequently reassigned both species to *Mesodonvillina* (*Protocynostrophia*) as they lacked a notably transverse outline and the trail was not as long as the central disk, an assessment also followed by Brock & Talent (1993). However, as discussed above, both species of Chatterton's (1973) are reassigned to *Cynostrophia* herein.

Brock & Talent (1993) also synonymised *C. (P.) multicostralla* with *C. (P.) dickinsi*, although Chatterton (1973) had separated them on slight differences in size, number of costellae, strength of the rugae, position of maximum width of the diductor scars and how much of the hinge line was denticulate. This synonymy appears justified as *C. (P.) multicostralla* is merely a smaller version of *C. (P.) dickinsi*.

Cynostrophia (Protocynostrophia) ivanensis (Barrande, 1879) closely resembles *C. (P.) dickinsi* externally, except that a greater portion of *C. (P.) ivanensis* is covered with rugae (Barrande 1879). The ventral valve muscle field of *C. (P.) ivanensis* tends to be more triangular in outline than that of *C. (P.) dickinsi* and is only divided by a fine myophragm, rather than a grooved median ridge. The dorsal valve muscle field of *C. (P.) dickinsi* is divided by a variably developed median ridge, whereas that of *C. (P.) ivanensis* is crossed by two narrow and slightly anteriorly divergent ridges which have a median septum located between them (Barrande 1879).

Cynostrophia (Protocynostrophia) has also been recovered from the Emsian Ukalunda Beds of Queensland (Brock & Talent 1993). Brock & Talent (1993) tentatively referred their material to *C. (P.) dickinsi* due to variation in outline and size of the ventral valve muscle field compared with that described by Chatterton (1973).

Subfamily PROTODOUVILLININAE Harper & Boucot, 1978b

Malurostrophia Campbell & Talent, 1967

Type species. By original designation of Campbell & Talent (1967: 309); *Malurostrophia flabellicauda* Campbell & Talent, 1967; early Emsian *Receptaculites* Limestone Member of the Taemas Limestone, Taemas, New South Wales, Australia.

Malurostrophia sp. cf. *M. flabellicauda* Campbell & Talent, 1967
Fig. 8G-K

cf. *Malurostrophia flabellicauda* sp. nov. Campbell & Talent 1967: 311, pl. 47, figs 1-16; pl. 48, figs 1-20; pl. 49, figs 1-8; pl. 50, figs 8-10.

?*Malurostrophia flabellicauda reverta* subsp. nov. Chatterton 1973: 50, pl. 9, figs 1-10.

cf. *Malurostrophia minima* sp. nov. Chatterton 1973: 52, pl. 10, figs 11-29.

?*Malurostrophia mura* sp. nov. Chatterton 1973: 54, pl. 10, figs 1-10.

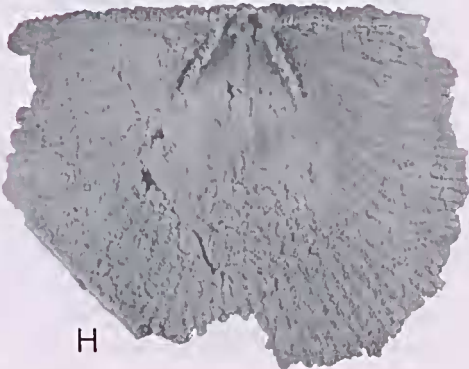
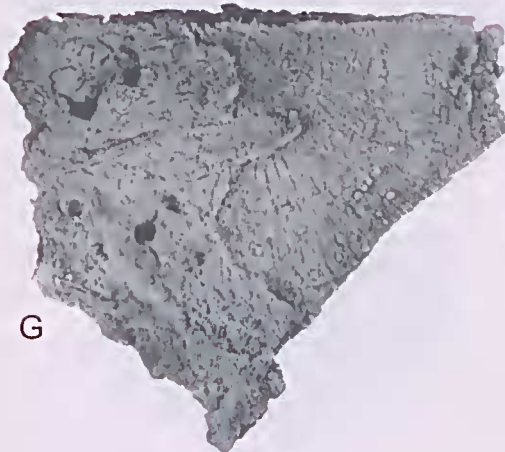
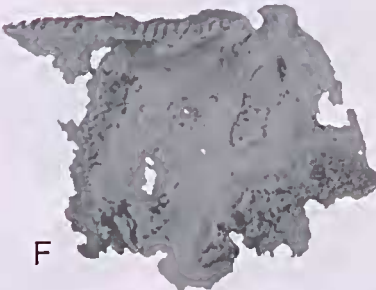
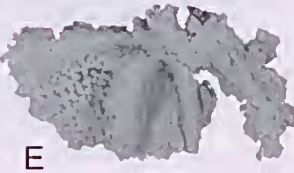
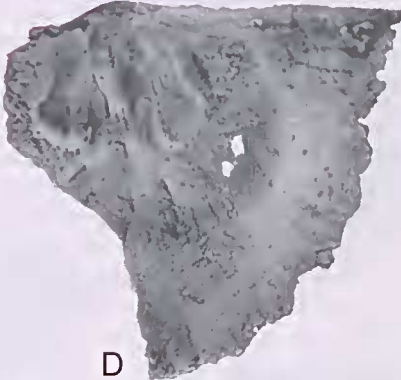
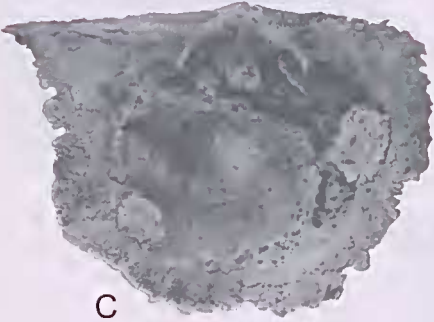
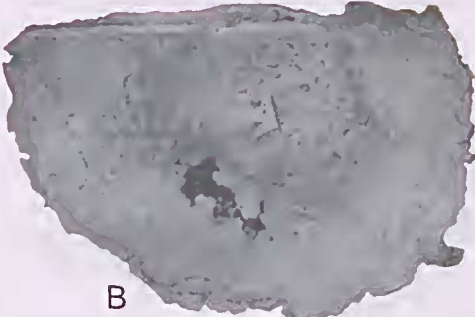
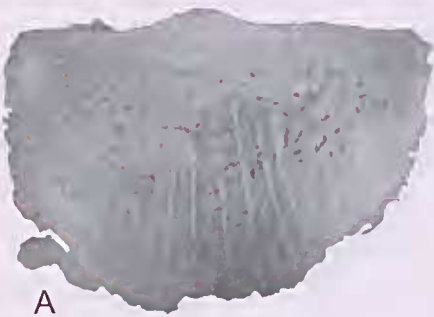
?*Malurostrophia bellu* sp. nov. Chatterton 1973: 55, pl. 11, figs 1-17.

Material. Figured material: AM F117259 (Fig. 8G, H): ventral valve from ROC 159; AM F117260 (Fig. 8I, J): articulated specimen from ROC 159. AM F126346 (Fig. 8K): ventral valve from ROC 176.9. Unfigured material: one ventral valve and three articulated specimens.

Description. See Chatterton (1973: 52).

Remarks. Chatterton (1973) described three new species of *Malurostrophia*, *M. bella*, *M. aura* and

Fig. 7. A-E, *Cynostrophia (Protocynostrophia) dickinsi* (Chatterton, 1973). A, B, dorsal and ventral views of articulated specimen, McL 417, AM F117250, x 2. C, ventral valve interior, ROC 159, AM F117251, x 2. D, ventral valve interior, ROC 162, AM F117252, x 2. E, cardinal process, ROC 159, AM F117253, x 4. F-H, *Mesoleptostrophia (Paraleptostrophia) clarki* (Chatterton, 1973). F, dorsal valve interior, McL 420dh, AM F117254, x 5. G, dorsal view of articulated specimen, ROC 159, AM F117255, x 2. H, ventral valve interior, ROC 159, AM F117256, x 2.



M. minima and a new subspecies of *M. flabellicauda*, *M. flabellicauda reverta*, from the Emsian 'Receptaculites' and Warroo Limestone Members of the Taemas Limestone at Taemas. Chatterton (1973) differentiated these species on size, length from the ventral valve beak to the beginning of the dorsal deflection of the anteriomedian portion of the shell, the degree of alation, the angle formed by the cardinal setal grooves with the hinge line, the presence or absence of a dorsal reversal in the growth of the lateral margins and the height to width and length to width ratios.

Although the specimens recovered from the Murrindal Limestone fall within the range of characteristics provided by Chatterton (1973) for *M. minima*, Talent et al. (2001) considered Chatterton's (1973) *Malurostrophia* species to be junior synonyms of *M. flabellicauda*. Examination of topotype material from Taemas confirms this observation. Indeed, the differences Chatterton (1973) used to distinguish the species are minor and the species appear to intergrade: *M. minima* to *M. flabellicauda* to *M. aura* to *M. flabellicauda reverta* and *M. bella*. In addition, Chatterton (1973) also mentioned the presence of intermediate forms that appear to link *M. minima* with *M. flabellicauda* and *M. flabellicauda* with *M. bella*.

Definite species allocation of the Murrindal specimens, however, is not possible due to previously unobserved morphological variations. The ventral valve muscle field of the Murrindal specimens ranges from 'waisted' (Fig. 8H) to 'non-waisted' (Fig. 8K), with the muscle field of 'waisted' forms being more strongly bilobate than the muscle field of 'non-waisted' forms (Fig. 8H, K). Only one of Campbell & Talent's (1967: pl. 49, fig. 5) specimens shows any 'waisting' of the ventral valve muscle field and this is only very weakly developed. Secondly, not all the Murrindal specimens are alate like those recovered by Chatterton (1973) and Campbell & Talent (1967) (Fig. 8H, J, K). Finally, the Murrindal specimens vary in their degree of resupination — alate forms are not as resupinate as non-alate forms.

The only other Early Devonian occurrence of *Malurostrophia* is *M. basilica* Campbell & Talent, 1967 from the Emsian Taravale Formation at

Buehan, Victoria. This species differs from *M. flabellicauda* in its greater size and in having less strongly developed ornament. Internally, *M. basilica* has more sinuous muscle bounding ridges in the dorsal valve than *M. flabellicauda* and the node at the anterior margin of the dorsal valve adductor scars is more strongly expressed (Campbell & Talent 1967).

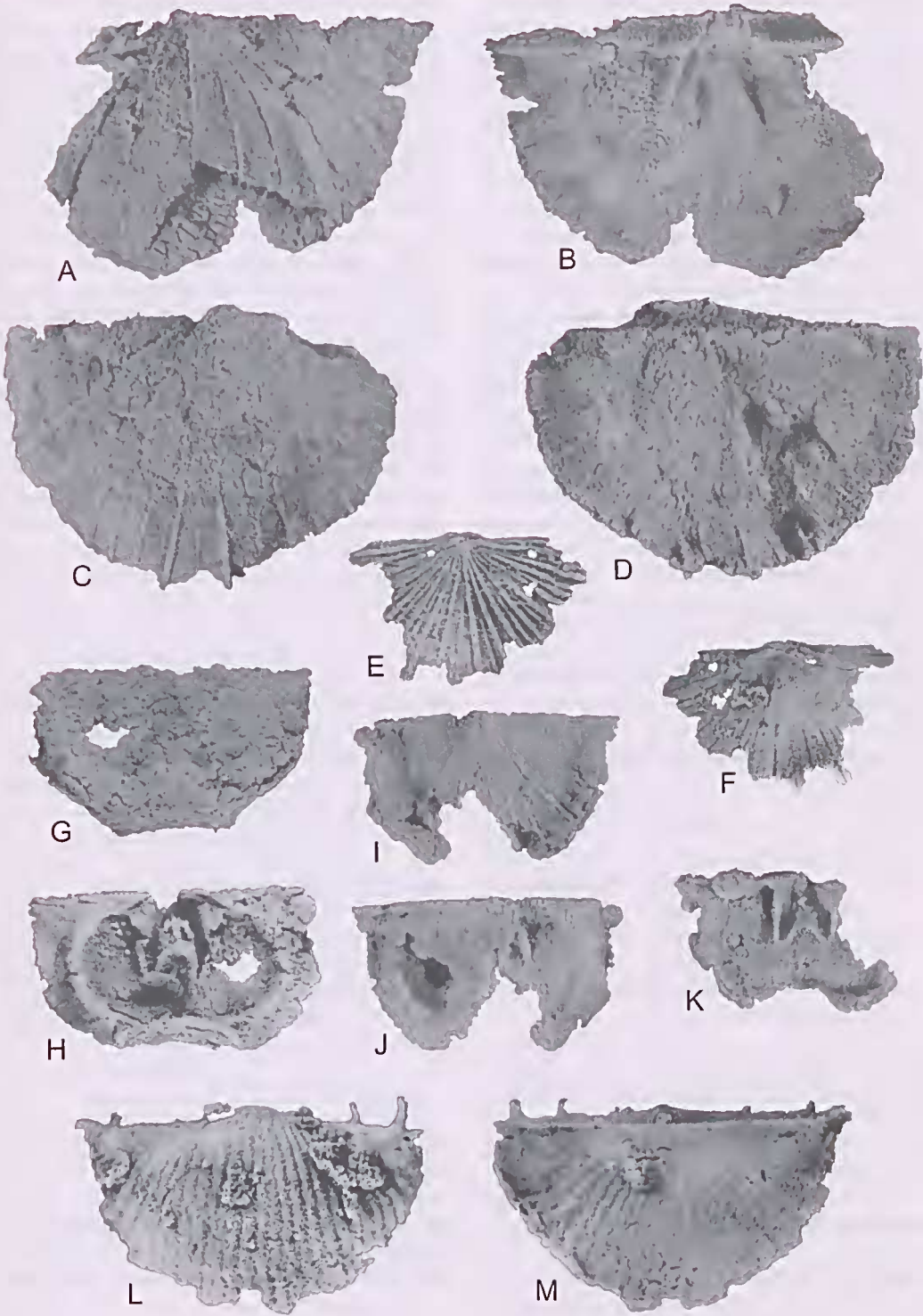
Nadiastrophia Talent, 1963

Type species. By original designation of Talent (1963: 62); *Nadiastrophia superba* Talent, 1963; Pragian Lower Kilgower Member of the Tabberabbera Formation, Victoria, Australia.

Remarks. Brock & Talent (1993) considered *Taemostrophia* Chatterton, 1973 a junior synonym of *Nadiastrophia*, contrary to Chatterton (1973) and Harper & Boucot (1978b), who accepted both genera on the basis that the ventral valve muscle field of *Taemostrophia* differed by being 'waisted'. From their study of specimens from the Emsian Ukalunda Beds and Douglas Creek of Queensland, Brock & Talent (1993) concluded that this feature is highly variable. Parfrey's (1989: pl. 1, figs 4–6) figures of *Taemostrophia* from the same area also show similar variation, whereas the single specimen figured by Hill et al. (1967: pl. D12, fig. 3), only shows slight 'waisting' of the ventral valve muscle field. Close examination of Chatterton's (1973: pl. 8, figs 1–19; pl. 13, figs 6–9) figures also reveals a high degree of variability in this feature. All specimens from the Murrindal Limestone assigned to *Nadiastrophia* lack this feature. Chatterton (1973) and Harper & Boucot (1978b) also suggested that *Taemostrophia* can be differentiated externally from *Nadiastrophia* by having a slightly raised central disk in the ventral valve and by being slightly depressed along the geniculate rim. Talent (1963: 62), however, described *Nadiastrophia* as possessing a slightly raised umbonal region in the ventral valve, which slopes towards the point of geniculation. Therefore, *Taemostrophia* should be considered synonymous with *Nadiastrophia*.

According to Wang (in Wang et al. 1974), the type species of *Xeuostrophia*, *X. yukiangensis*

Fig. 8. A–D, *Nadiastrophia patmorei* (Chatterton, 1973). All specimens x 5. A, B, ventral valve exterior and interior, ROC 159, AM F117257. C, D, ventral and dorsal views of articulated specimen, ROC 159, AM F117258. E, F, *Eoschuchertella murphyi* (Chatterton, 1973), dorsal valve interior and exterior, ROC 165, AM F117261, x 5. G–K, *Malurostrophia* sp. cf. *M. flabellicauda* Campbell & Talent, 1967. All specimens x 5. G, H, ventral valve exterior and interior, ROC 159, AM F117259. I, J, ventral and dorsal views of articulated specimen, ROC 159, AM F117260. K, ventral valve interior, ROC 176.9, AM F126346. L, M, *Johnsonetes australis* (McCoy, 1876), ventral and dorsal views of articulated specimen, ROC 165, AM F117262, x 5.



(Wang, 1956) from the Emsian Yükiang Formation of Kwangsi Province, China, differs from *Nadiastrophia* by being larger, having a less prominent beak, a widely rectangular ventral valve muscle field, shallow pallial markings and having a dorsal valve muscle field which is not elevated on a platform. Harper & Boucot (1978b), however, referred *X. yukiangensis* to *Nadiastrophia*. Examination of the ventral valve muscle field of *X. yukiangensis* shows its outline to be variable. The ventral valve muscle field of the two specimens figured by Wang et al. (1974: pl. 5, figs 4, 5) differs from the ventral muscle field of *N. superba* in being longer, broader and in having the widest point located behind valve midlength. On the other hand, the ventral valve muscle field of the specimen figured by Hou & Zian (1975: pl. 5, fig. 10) is more in keeping with *Nadiastrophia* than *Xenostrophia*, being shorter and thinner, with the widest point at the midlength. Rong & Cocks (1994) believed that generic distinction amongst strophomenoids can only be made on internal features, including the presence or absence of dental or socket plates, muscle bounding ridges, side septa or diaphragms; character states like ornament, dimensions, shell shape and the relative proportion of internal structures can be useful discriminators at the species level. *Xenostrophia* can be questionably considered synonymous with *Nadiastrophia*.

***Nadiastrophia patmorei* (Chatterton, 1973)**

Fig. 8A-D

Nadiastrophia sp. nov. Hill, Playford & Woods 1967: pl. D12, figs 3, 4.

Taenostrophia patmorei sp. nov. Chatterton 1973: 44, pl. 8, figs 1-9; pl. 13, figs 6-9.-Harper & Boucot 1978b: 143, pl. 28, figs 11, 13-16.-Parfrey 1989: pl. 1, figs 1, 2, 4, 7.

Nadiastrophia patmorei-Broek & Talent 1993: 235, fig. 10P-T.

Material. Figured material: AM F117257 (Fig. 8A, B); ventral valve from ROC 159; AM F 117258 (Fig. 8C, D); articulated specimen from ROC 159. Unfigured material: 31 ventral valves and five articulated specimens.

Description. See Chatterton (1973: 44).

Remarks. *Nadiastrophia superba* from the Pragian Lower Kilgower Member of the Tabberabbera Formation, Victoria (Talent 1963), the Pragian Garra Lime-

stone (Lenz & Johnson 1985a) and the Loehkovian Garra Limestone at Eurimbla, New South Wales (Broek 2003a), closely resembles *N. patmorei* from several Emsian localities of eastern Australia (see Hill et al. 1967: d.24; Chatterton 1973: 43; Parfrey 1989: 201; Broek & Talent 1993: 231). They differ, however, in that *N. superba* possesses a more strongly bilobate muscle field in the ventral valve and a greater proportion of the hinge line is denticulate (almost whole length versus half). The dorsal valve of *N. superba* has a laterally directed cardinal process, whereas the lobes are ventrally directed in *N. patmorei* and the socket ridges of *N. superba* diverge at a slightly shallower angle than in *N. patmorei*.

Numerous species of *Nadiastrophia* have been described from Early and Middle Devonian strata of China (see Wang et al. 1987 and Chen et al. 1989 and references therein). They tend to differ from both *N. patmorei* and *N. superba* in possessing less well-developed costellae and are not as strongly transverse or alate. Most also possess a more strongly bilobate ventral valve muscle field than *N. patmorei* and also tend to lack the degree of variation observed by Hill et al. (1967), Chatterton (1973), Parfrey (1989) and Broek & Talent (1993) in the muscle field outline of the ventral valve.

Nadiastrophia insignis Kaplun (in Kaplun & Krupchenko, 1991), from the Lower Devonian Balkhash region of Kazakhstan, is similar to *N. patmorei* externally, although it is not as transverse or alate. However, the ventral valve muscle field of *N. insignis* appears to be variably bilobate, extending for most of the valve length, and lacks evidence of 'waisting'. In addition, the ventral valve muscle field of *N. insignis* is bounded posteriorly and anteriorly by ridges.

Harper et al. (1967: 425) also mentioned the possible occurrence of *Nadiastrophia*, based on a single internal mould of a ventral valve, from the early Emsian Reefton Group of New Zealand. As Harper et al. (1967) did not describe or figure this species, comparisons are not possible.

Family LEPTOSTROPHIIDAE Caster, 1939

***Mesoleptostrophia* (*Paraleptostrophia*) Harper & Boucot, 1978a**

Type species. By original designation of Harper & Boucot (1978a: 70); *Leptostrophia clarkei* Chatterton, 1973; early Emsian Warroo Limestone Member of the Taemas Limestone, Taemas, New South Wales, Australia.

Remarks. Harper & Boucot (1978a) erected *Mesoleptostrophia* for gently concavo-convex leptostrophiinids with socket plates and a triangular muscle field in the ventral valve bounded laterally by ridges. Harper & Boucot (1978a) also divided *Mesoleptostrophia* into two subgenera, *M.* (*Mesoleptostrophia*), which has divergent socket plates relative to the lateral margins of the cardinal process and *M.* (*Paraleptostrophia*), which possesses socket plates lying parallel to the lateral margins of the cardinal process. Cocks & Rong (2000) separated these genera primarily on the basis of the cardinal process lobes—strongly posteriorly directed in *M.* (*Paraleptostrophia*) and relatively small and ventro-posteriorly directed in *M.* (*Mesoleptostrophia*).

Unlike *M.* (*Mesoleptostrophia*), *M.* (*Paraleptostrophia*) has a relatively restricted distribution, occurring only in Burma (Reed 1908; Anderson et al. 1969; Harper & Boucot 1978a) and Kazakhstan (Kaplun & Krupchenko 1991), in addition to Australia.

Mesoleptostrophia* (*Paraleptostrophia*) *clarkei
(Chatterton, 1973)
Fig. 7F-H

?*Leptostrophia* sp. Whitehouse 1929: 159.

Leptostrophia clarkei sp. nov. Chatterton 1973: 58,
pl. 12, figs 1–13; pl. 13, figs 10–17; pl. 35,
figs 12–14.

Mesoleptostrophia (*Paraleptostrophia*) *clarkei*-Parfrey 1989: pl. 1, figs 7–17, 19–21.-Brock & Talent 1993: 236, fig. 10U, V.

Material. Figured material: AM F117254 (Fig. 7F): dorsal valve from McL 420dh; AM F117255 (Fig. 7G): articulated specimen from ROC 159; AM F117256 (Fig. 7H): ventral valve from ROC 159. Unfigured material: 29 ventral valves, seven dorsal valves and four articulated specimens.

Description. See Chatterton (1973: 58).

Remarks. Harper & Boucot (1978a) reassigned *Leptostrophia clarkei* from the Emsian 'Receptaculites' and Warroo Limestone Members of the Taemas Limestone at Tamas (Chatterton 1973) and the Emsian Ukalunda Beds and Douglas Creek of Queensland (Whitehouse 1929; Parfrey 1989; Brock & Talent 1993) to *M.* (*Paraleptostrophia*), based on the

socket plates of this species lying subparallel to the lateral margins of the cardinal process lobes. Specimens from the Murrindal Limestone are in general poorly preserved, the dorsal valves in particular, but the socket plates are still observable and lie subparallel to the lateral margins of the cardinal process (Fig. 7F).

In his original description of *M.* (*P.*) *clarkei*, Chatterton (1973) did not mention the bilobed nature of the muscle field in the ventral valve. Although this feature appears to be variable, it is clearly observable in Chatterton's (1973: pl. 12, fig. 1; pl. 13, figs 16, 17) figured material. A variably bilobate ventral valve muscle field also occurs in specimens from the Emsian Ukalunda Beds and Douglas Creek of Queensland (see Parfrey 1989: pl. 1, figs 8, 9, 16 and Brock & Talent 1993: fig. 10U, V). Material from the Murrindal Limestone also displays some degree of bilobation to the ventral valve muscle field (Fig. 7H).

Externally, *M.* (*P.*) *clarkei* is very similar to *M.* (*P.*) *padankpinensis* Anderson, Boucot & Johnson, 1969, from the Eifelian Padaukpin Limestone of Burma, although the ornament of *M.* (*P.*) *clarkei* is slightly coarser. Both valves of *M.* (*P.*) *padankpinensis* possess only short myophores, whereas both valves of *M.* (*P.*) *clarkei* have a median ridge. *Mesoleptostrophia* (*Paraleptostrophia*) *lepsensis* Krupchenko (in Kaplun & Krupchenko, 1991), from the Early Devonian northern Balkhash region of Kazakhstan, has a greater proportion of its hinge line covered with denticles than *M.* (*P.*) *clarkei* (full length versus three-quarters); the muscle scars, though similar in outline, are not as deeply impressed as in *M.* (*P.*) *clarkei*.

Order PRODUCTIDA Sarytcheva & Sokolskaya, 1959

Suborder CHONETIDINA Muir-Wood, 1955

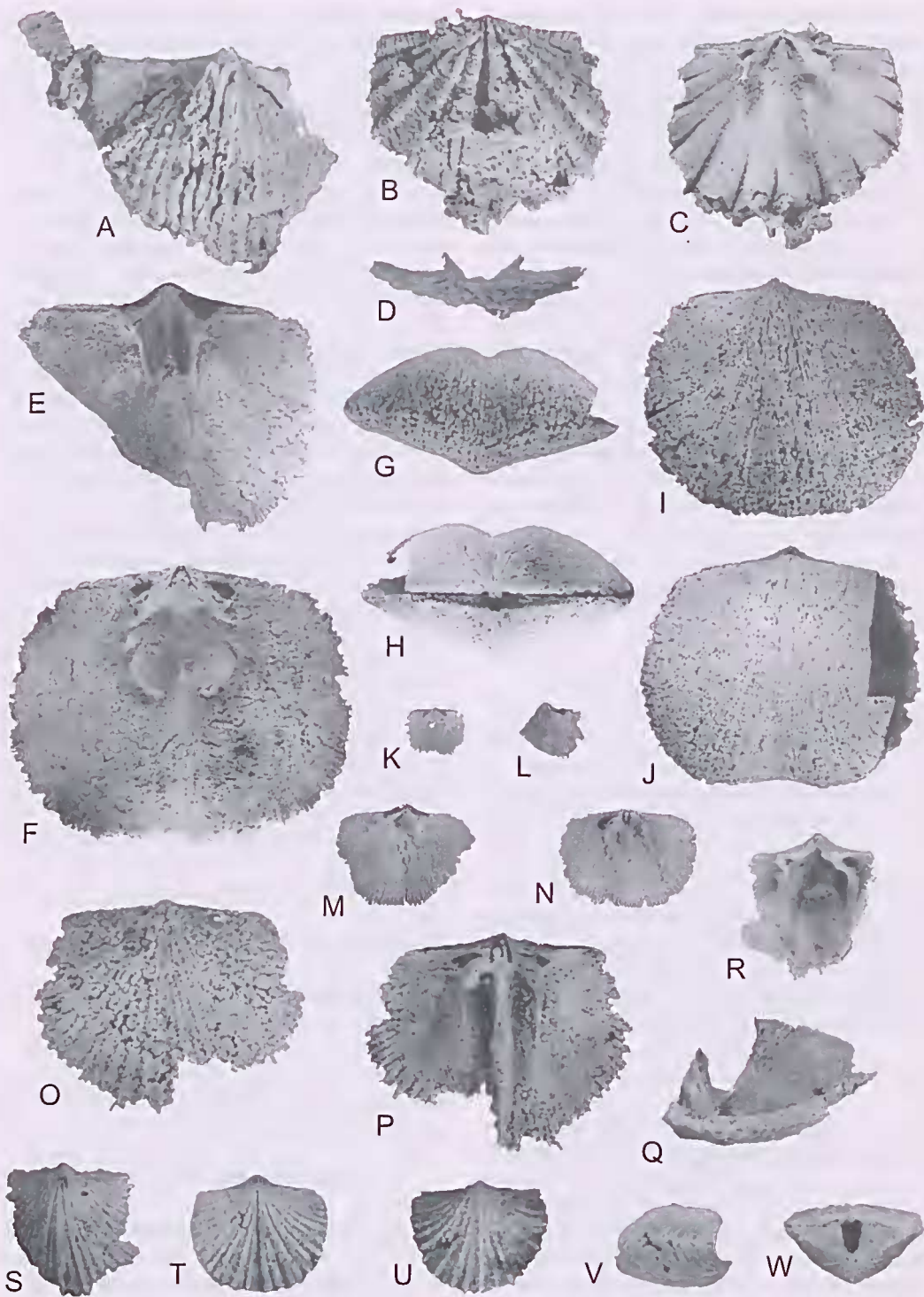
Superfamily CHONETOIDEA Bronn, 1862

Family STROPHOCHONETIDAE Muir-Wood, 1962

Subfamily STROPHOCHONETINAE Muir-Wood, 1962

Johnsonetes Rachebocuf, 1987

Type species. By original designation of Rachebocuf (1987: 7); *Chonetes filistriata* Walcott, 1884; Emsian of Comb's Peak, Eureka District, Nevada, America.



Johnsonetes australis (McCoy, 1876)

Fig. 8L, M

Chonetes australis sp. nov. McCoy 1876: 141, pl. 35, figs 3–5. Gill 1951: 64, pl. 3, figs 18, 19, 21. Talent 1956a: 41, pl. 3, figs 10, 11.

Chonetes teichertii sp. nov. Gill 1951: 70, pl. 3, figs 12–15.

?*Protochonetes* sp. Broek & Talent 1993: 236, fig. 11C–E.

Johnsonetes australis Strusz 2000: 257, figs 8, 9.

Material. Figured material: AM F117262 (Fig. 8L, M): articulated specimen from ROC 165. Unfigured material: 23 ventral valve fragments and 12 articulated specimens.

Description. See Gill (1951: 64), Talent (1956a: 41) and Strusz (2000: 257).

Remarks. Following Strusz (2000), this species is assigned to *Johnsonetes* as the hinge spines are inserted asymmetrically and spine 1' is absent, the cardinal process is supported by anteriorly divergent, rounded, inner socket ridges and the median costa is enlarged only posteriorly. *Johnsonetes australis* is distinguishable from *J. filistriata* in possessing a greater number of hinge spines and fewer, coarser costae that increase in number occasionally by bifurcation. No trace of the faint undulating concentric striae observed by Walcott (1884) and illustrated by Johnson (1970a: pl. 31, figs 9, 12) in *J. filistriata*, are present in *J. australis*.

Johnsonetes australis is closely related to *J. cullenii* (Dun, 1904) from the Emsian 'Spirifer' yassenensis, 'Receptaculites' and Warroo Limestone Members of the Taemas Limestone at Taemas. Both have a similar size, shape, tendency to develop a weak ventral valve sulcus and a prominent notothyrial platform (Strusz 2000). Dun (1904) confidently separated the two on the basis that *J. cullenii* is more strongly convex, possesses fewer and coarser ribs and is less flattened towards the cardinal angles, but Chatterton (1973) regarded *J. cullenii* as possibly

being synonymous with *J. australis*. He differentiated them by the anderidia of *J. australis* being located on a pair of low ridges and the socket ridges being more prominent than those of *J. cullenii*. Broek & Talent (1993) and Talent et al. (2001) considered *J. cullenii* synonymous with *J. australis* and the observed differences a result of intraspecific variation. However, despite rejecting the differences cited by Dun (1904), Strusz (2000) considered *J. australis* and *J. cullenii* distinct. In addition to the differences observed by Chatterton (1973), Strusz (2000) stressed the flat ventral valve interarea and the prominent protogular structures of the dorsal and ventral valves in *J. australis* and the weakly concave ventral valve interarea of *J. cullenii* and obscure protogular structures of both valves.

Johnsonetes australis is so similar to *J. latus* (Chatterton, 1973) from the Emsian 'Receptaculites' Limestone Member of the Taemas Limestone at Taemas, that Talent et al. (2001) synonymised *J. latus* with *J. australis*. However, Strusz (2000) considered *J. latus* distinct, being small, transverse with distinctly triangular alae and having few hinge spines and deep furrows developed between the ribs. Internally, strongly developed anderidia and the median septum are fused to a prominent notothyrial platform (Strusz 2000).

Johnsonetes australis is also closely related, possibly even synonymous with, an unnamed species referred to *Protochonetes* Muir-Wood, 1962 by Broek & Talent (1993) from the Emsian Ukalunda Beds and Douglas Creek of Queensland. They are similar in size, the development of a sulcus in the ventral valve and internal features of the ventral valve. However, the adductor muscle scars in the ventral valve of *P. australis* tend to be more divergent (Broek & Talent 1993) and the ventral valve median septum to be thicker and shorter. The interior of the dorsal valve and the nature of the hinge spines are not known in the specimens from the Ukalunda Beds and Douglas Creek (Strusz 2000).

Strusz (2000) questionably referred ?*Devonochonetes* sp. 2 of Lenz and Johnson (1985a) from the Pragian Garra Limestone at Wellington to

Fig. 9. A, *Johnsonetes?* sp. cf. *J. cullenii* (Dun, 1904), dorsal valve interior, ROC 165, AM F117263, x 5. B–D, *Hesperorthidae* gen. et sp. indet., exterior, interior and posterior views of dorsal valve, ROC 174.1, AM F117264, x 4. E–N, *Tyrsella spedenii* Chatterton, 1973. All specimens x 2. E, ventral valve interior, ROC 181, AM F117265. F, dorsal valve interior, ROC 181, AM F117266. G–J anterior, posterior, ventral and dorsal views of articulated specimen, ROC 181, AM F117267. K, dorsal valve interior, ROC 159, AM F126347. L, ventral valve interior, ROC 159, AM F126348. M, ventral valve interior, ROC 159, AM F126349. N, dorsal valve interior, ROC 159, AM F126350. O–W, *Prokopia hillae* (Chatterton, 1973). All specimens x 6. O–Q, exterior, internal and lateral views of dorsal valve, ROC 174.1, AM F117268. R, S, ventral valve interior and exterior, McL 420dh, AM F117269. T–W, dorsal, ventral, lateral and posterior views of articulated specimen, McL 420dh, AM F117270.

Johnsonetes on the presence of a prominent nothothyrial platform, wide cardinal process, a well-developed dorsal valve medium septum and a weakly impressed ventral valve muscle field. It thus closely resembles both *J. australis* and *J. cullenii*, but *J. australis* is larger and more coarsely ornamented (Strusz 2000).

Johnsonetes ellesmerensis Racheboeuf, 1987, from the Emsian lower member of the Blue Fiord Formation, Ellesmere Island in the Canadian Arctic Archipelago, is smaller and less strongly concavo-convex than *J. australis*. Internally, *J. ellesmerensis* has a shorter median septum in the dorsal valve and anderidia that are not located on broad ridges. *Johnsonetes arcticus* Racheboeuf, 1987, which occurs higher in the Blue Fiord Formation, may be distinguished from *J. australis* by its larger size, concave ventral interarea and slightly more numerous ribs. Internally, it can be distinguished by teeth which are oval in cross section, a weakly bilobed cardinal process, anderidia that are not located on broad ridges, and by the lack of papillae on the inner surface of the dorsal valve.

Johnsonetes? sp. cf. *J. cullenii* (Dun, 1904)
Fig. 9A

?*Chonetes cullenii* sp. nov. Dun 1904: 321, pl. 61, figs 1, 1a.

?*Protochonetes cullenii*-Chatterton 1973: 69, pl. 16, figs 1–22.

?*Johnsonetes cullenii*-Strusz 2000: 260, figs 9, 10.

Material. Figured material: AM F117263 (Fig. 9A): dorsal valve from ROC 165.

Description. See Chatterton (1973: 69) and Strusz (2000: 260).

Remarks. The long, posteriorly widened median septum of the dorsal valve, short, wide cardinal process to which anteriorly divergent anderidia are fused, and low rounded socket ridges of this specimen (Fig. 9A) are all reminiscent of *Johnsonetes*, particularly *J. australis* and *J. cullenii*. The well-developed alae of this specimen suggest that its affinities lie with *J. australis* but, as the anderidia are not raised on ridges, its affinities therefore appear to lie with *J. cullenii*. However, as no hinge spines or bases have been preserved in this specimen (Fig. 9A), its assignment to *Johnsonetes* must remain doubtful.

Order ORTHOTETIDA Waagen, 1884
Suborder ORTHOTETIDINA Waagen, 1884
Superfamily CHILIDIOPSOIDEA Boucot, 1959
Family AREOSTROPHIIDAE Manankov, 1979
Subfamily ADECTORHYNCHINAE Henry & Gordon, 1985

Eoschuchertella Gratsianova, 1974

Type species. By original designation of Gratsianova (1974: 83); *Eoschuchertella popovi* Gratsianova, 1974; late Emsian Malokorgonsk beds of Gorno-Altai, southwestern Siberia, Russia.

Remarks. *Eoschuchertella* was proposed by Gratsianova (1974) to separate impunctate forms resembling the pseudopunctate *Schuchertella* Girty, 1904. It is upon this basis that the following species has been reassigned to *Eoschuchertella*.

Eoschuchertella murphyi (Chatterton, 1973)
Fig. 8E, F

Schuchertella murphyi sp. nov. Chatterton 1973: 63, pl. 14, figs 1–17.

?*Eoschuchertella* cf. *E. murphyi*-Perry 1979: pl. 1, figs 22–25.-?Perry 1984: 50, pl. 15, figs 13–19.

Material. Figured material: AM F117261 (Fig. 8E, F): dorsal valve from ROC 165. Unfigured material: two ventral valves and four dorsal valves.

Description. See Chatterton (1973: 63).

Remarks. *Eoschuchertella popovi* differs from *E. murphyi* in possessing fine costellae arising by bifurcation in both valves, whereas the costellae of *E. murphyi* are coarser and arise through both bifurcation and intercalation in both valves (Fig. 8F). Internally, *E. popovi* has a more strongly bilobate cardinal process than *E. murphyi* and a less strongly convex pseudodeltidium. The internal surface of *E. murphyi* is strongly and coarsely crenulate, especially around the margins (Fig. 8E), whereas the internal surface of *E. popovi* is more finely and evenly crenulate.

Eoschuchertella murphyi is very similar to *E. burrenensis* (Savage, 1971) from the Early Devonian Garra Limestone tongue at Manildra (Savage 1971), The Gap (Farrell 1992) and Eurimbla (Brook 2003a), particularly in possessing recurved socket

plates, features of the cardinalia, number and size of costellae, and the lack of dental lamellae (Chatterton 1973). Chatterton (1973) separated them primarily on the maximum size attained by mature individuals, with the largest specimens of *E. murphyi* from the Emsian 'Receptaculites' and Warroo Limestone Members of the Taemas Limestone at Taemas being less than half the size of some specimens figured by Savage (1971: pl. 73, figs 1–21). Despite only a small number of specimens having been recovered from the Murrindal Limestone, their size (the largest specimen recovered, although incomplete, measures 7 mm in width and 4 mm in length) suggests assignment to *E. murphyi*.

Eoschuchertella is a common component of Early and Middle Devonian strata throughout Canada and Alaska (Chatterton & Perry 1978). Perry (1984) documented three species of *Eoschuchertella* from the Pragian to Emsian sequences of the Delorme Formation, one of which was questionably referred to *E. murphyi*. Perry's (1984) *E. sp. cf. E. murphyi* and the Australian material are identical in terms of ornament, lack of dental lamellae and muscle scars. The Delorme specimens differ though in having only a weakly bilobed cardinal process, a feature regarded as being of taxonomic significance by Williams & Brunton (1993) and Brunton & Cocks (1996).

Another unnamed species of *Eoschuchertella* from the early Pragian Heeceta Island of southeastern Alaska was described by Savage (1981) as being identical to *E. burruensis* and to material described by Johnson (1970a) from Nevada and Lenz (1977a) from the Yukon.

Class RHYNCHONELLATA Williams, Carlson,
Brunton, Holmer & Popov, 1996

Order ORTHIDA Schuchert & Cooper, 1932

Suborder ORTHIDINA Schuchert & Cooper, 1932

Superfamily ORTHOIDEA Woodward, 1852

Family HESPERORTHIDAE Schuchert &
Cooper, 1931

Dolerorthis sp.

Fig. 10N–U

Material. Figured material: AM F117276 (Fig. 10N–R); articulated specimen from McL 417; AM F117277 (Fig. 10S, T); ventral valve from ROC 162; AM F117278 (Fig. 10U); dorsal valve from McL 417. Unfigured material: 11 ventral valves, one dorsal valve and four articulated specimens.

Remarks. The ventri-biconvex lateral profile, triangular apsacline ventral valve interarea with an open delthyrium (Fig. 10P, S) and dorsal valve with an anacline interarea and notothyrial platform bearing a blade-like cardinal process (Fig. 10U) indicates affinities with *Dolerorthis* (Schuchert & Cooper 1932; Amsden 1968, 1974; Johnson et al. 1973). However, unlike many other *Dolerorthis*, such as *D. borealis* Lenz, 1977a, from the upper Lochkovian and lower Pragian strata of the Delorme Formation (Lenz 1977a; Perry 1984) and the Lochkovian Garra Limestone at Wellington (Lenz & Johnson 1985a) and Eurimbla (Brock 2003a) and *D. ornata* Lenz & Johnson, 1985a from the Lochkovian Garra Limestone at Wellington, the Murrindal specimens lack third and fourth order costellae (Fig. 10Q, R, T). The first order costellae are well-developed and second order costellae arise at varying distances from the beak through bifurcation and intercalation. The Murrindal specimens differ further in possessing a curved ventral valve interarea cleft by a triangular delthyrium, rather than a slit-like delthyrium with subparallel margins (Fig. 10P, S), by lacking well-developed growth lamellae (Fig. 10Q, R, T) and by their smaller size (ventral valves average 5.33 mm wide and 4.04 mm long; dorsal valves average 5.81 mm wide and 4.06 mm long).

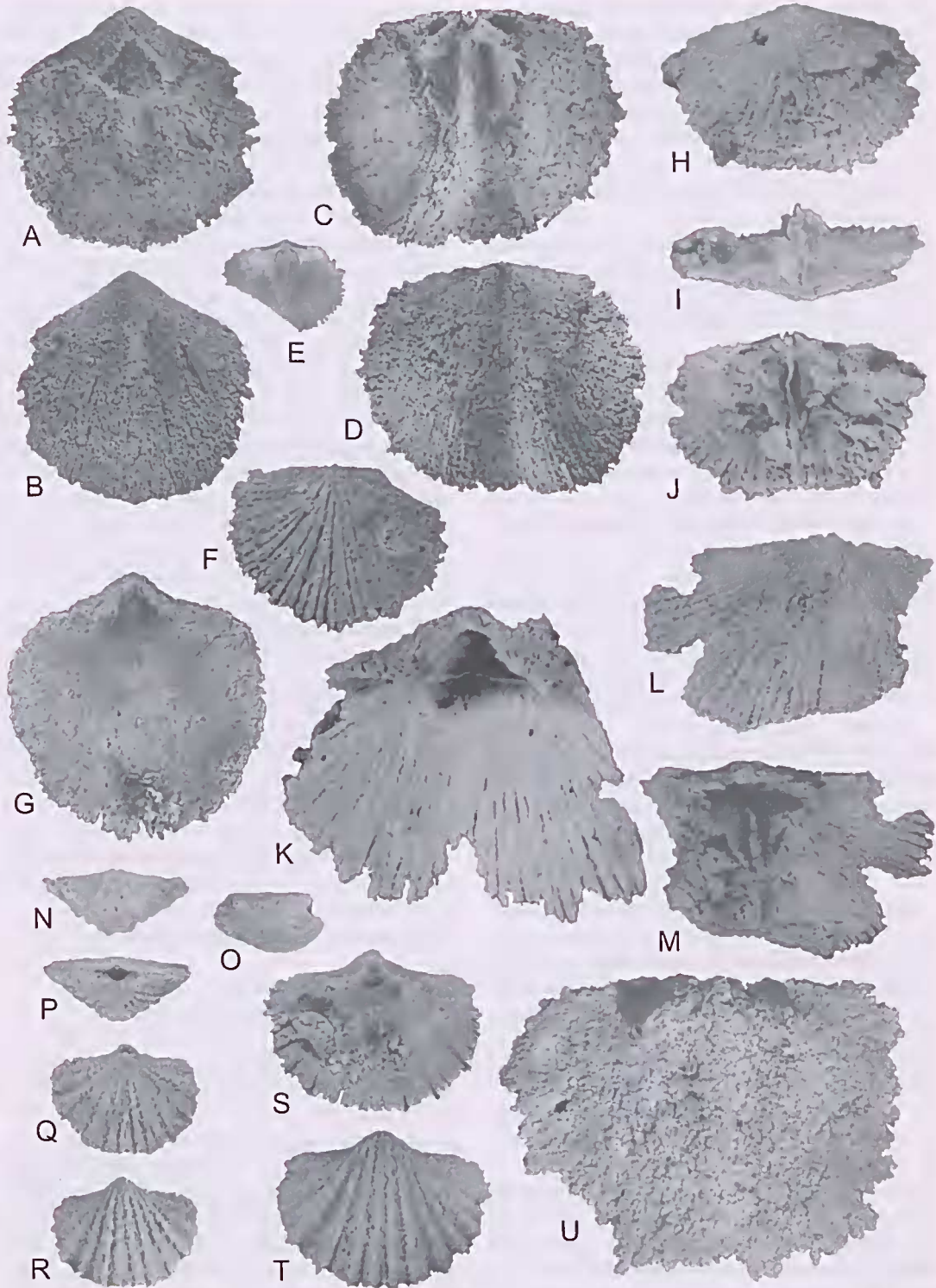
The Murrindal specimens are most similar to *D. persculpta* Philip, 1962 from the latest Lochkovian to earliest Pragian Boola siltstone of the Tyers-Boola area, central Victoria. Both species lack third and fourth order costellae and possess a curved ventral valve interarea cleft by a triangular delthyrium. The Murrindal specimens differ primarily from *D. persculpta* in their slightly smaller size, fewer primary costae and lack of growth lamellae. Additional material, particularly dorsal valves, are required before a more positive identification is possible.

Hesperorthidae gen. et sp. indet.

Fig. 9B–D

Material. Figured material: AM F117264 (Fig. 9B–D); dorsal valve from ROC 174.1.

Remarks. The internal features of this dorsal valve resemble *Dolerorthis* in possessing well-developed, divergent brachioophores, a simple ridge-like cardinal process, a low broad, indistinct median ridge extending to valve midlength and long narrow adductor scars (Fig. 9C). It differs from *Dolerorthis* though in possessing only primary costae (Fig. 9B). The costae of this specimen all arise in the beak



area, whereas the primary costae of *Dolerorthis* arise through bifurcation of and/or intercalation between those originating in the beak area. Zhang (1989) erected *Flabellitesia* for hesperorthids with simple costae, an antygidium and a dorsi-biconvex to resupinate profile. The Murrindal specimen though is flat in profile and lacks an antygidium (Fig. 9D). *Hesperorthis* Schuchert & Cooper, 1931, also possesses simple costae, but differs in possessing an antygidium as well.

This combination of features suggests the Murrindal specimen may represent a new genus of hesperorthid with simple costae and lacking an antygidium. Additional material is required to confirm this.

Suborder DALMANELLIDINA Moore, 1952
Superfamily DALMANELLOIDEA
Schuchert, 1913
Family DALMANELLIDAE Schuchert, 1913
Subfamily ISORTHINAE Schuchert &
Cooper, 1931

Tyersella Philip, 1962

Type species. By original designation of Philip (1962: 197); *Tyersella typica* Philip, 1962; Pragian Coopers Creek Formation, Tyers-Boola area, central Victoria, Australia.

Remarks. Philip (1962) noted that *Tyersella* was likely to be closely related to *Isorthis* due to similarities in ornament, muscle scars, cardinal process and the digitate dorsal pallial sinuses. Talent (1965b: 23) believed *Tyersella* was 'a typical Isorthis' and therefore considered *Tyersella* a subgenus of *Isorthis*. Despite Johnson et al. (1973: 18) claiming *Tyersella* was 'morphologically distinct from *Isorthis*', Walmesley & Boucot (1975) considered *Tyersella* a subgenus of *Isorthis*, based primarily on similarities between the muscle fields of both valves. They distinguished *I. (Tyersella)* from the other subgenera of *Isorthis*, *I. (Isorthis)*, *I. (Protocortezortis)*, *I. (Ovalella)* and *I. (Arcuella)*, on features of the dorsal valve muscle field and the sockets being excavated in the valve floor. Havlíček (1977), Smith

(1980), Kaplun & Krupchenko (1991) and Williams & Harper (2000) have all maintained *Tyersella* as a separate genus, which is followed here. This assessment is based on differences in shell convexity, the presence or absence of fuleral plates and differences in the dorsal valve muscle field.

Tyersella spedeni (Chatterton, 1973) Fig. 9E-N

Isorthis spedeni sp. nov. Chatterton 1973: 19, pl. 1, figs 8–22; pl. 2, figs 1–14; pl. 5, figs 16–24; pl. 35, fig. 13.

?*Isorthis* sp. Parfrey 1989: pl. 1, fig. 3.

Isorthis (Tyersella) spedeni-Broek & Talent 1993: 233, fig. 91-O.

Material. Figured material: AM F117265 (Fig. 9E): ventral valve from ROC 181; AM F117266 (Fig. 9F): dorsal valve from ROC 181; AM F117267 (Fig. 9G-J): articulated specimen from ROC 181. AM F126347 (Fig. 9K): dorsal valve from ROC 159. AM F126348 (Fig. 9L): ventral valve from ROC 159. AM F126349 (Fig. 9M): ventral valve from ROC 159. AM F126350 (Fig. 9N): dorsal valve from ROC 159. Unfigured material: 238 ventral valves, 257 dorsal valves and 21 articulated specimens.

Description. See Chatterton (1973: 19).

Remarks. *Tyersella typica* is larger than *T. spedeni* and is nonsulcate. The dorsal valve median ridge of *T. typica* extends beyond the anterior margin of the muscle field (Broek & Talent 1993). In addition, *T. spedeni* differs from most other *Tyersella*, such as *T. concinna* (Hall, 1859b) and *T. perelegans* (Hall, 1857), in possessing a well-developed sulcus in the dorsal valve, and having sockets raised on secondary shell material, instead of being excavated in the valve floor.

Ontogeny. Neanic specimens of *T. spedeni* recovered from the Murrindal Limestone are ventribiconvex, with a variably developed shallow sulcus in the dorsal valve. Less than a dozen primary costellae are present with secondary costellae arising through

Fig. 10. A-G, *Resserella careyi* Chatterton, 1973. All specimens x 2. A, B, ventral valve interior and exterior, ROC 162, AM F117271. C, D, dorsal valve interior and exterior, ROC 162, AM F117272. E, ventral valve interior, ROC 159, AM F126351. F, dorsal valve exterior, ROC 159, AM F126352. G, ventral valve interior, ROC 159, AM F126353. H-M, *Biernatium catastum* sp. nov. All specimens x 8. H-J, holotype, exterior, posterior and interior views of dorsal valve, MeL 520, AM F117274. K, ventral valve interior, MeL 520, AM F117273. L, M, dorsal valve exterior and interior, MeL 520, AM F117275. N-U, *Dolerorthis* sp. All specimens x 5. N-R, anterior, lateral, posterior, dorsal and ventral views of articulated specimen, MeL 417, AM F117276. S, T, ventral valve interior and exterior, ROC 162, AM F117277. U, dorsal valve interior, MeL 417, AM F117278.

intercalation and subdivision. The teeth are small, triangular and supported by short and strongly divergent dental plates. The ventral valve muscle field is bilobate, with the diductor sears being separated by a low ridge upon which the adductor sears are located, with no muscle bounding ridges (Fig. 9L). The cardinal process is simple and nonlobed. The brachioophores are strongly divergent and supported by small brachioophore plates that extend forward as low muscle bounding ridges. The midpoint of the muscle bounding ridges is notched, marking the boundary between the posterior and anterior pair of adductor sears that are otherwise indistinguishable. The sockets are variably raised on secondary shell material (Fig. 9K).

Sub-adult *T. spedeni* are subequally biconvex, the dorsal valve becoming more strongly convex compared to neanic specimens. The ventral valve muscle field is more firmly impressed and elongate than in neanic specimens and weakly developed muscle bounding ridges are present laterally (Fig. 9K). The cardinal process has become bilobed and elevated on a notothyrial platform. The dorsal valve median ridge is enlarged and the adductor sears are separated by weakly developed ridges divergent from the median ridge at 90°. The sockets of juvenile specimens are raised on secondary shell material and lack fuleral plates (Fig. 9N).

The same growth patterns observed in sub-adult *T. spedeni* continue into adults. In particular, adult specimens are almost equally biconvex, the ventral valve remaining slightly more strongly convex than the dorsal valve (Fig. 9G, H). Internally, the muscle fields of both valves have become more firmly impressed and the muscle bounding ridges are more strongly developed (Fig. 9E, F). Gerontic specimens appear very similar to adult specimens, but have more deeply impressed muscle sears and more strongly developed muscle-bounding ridges in both valves. The cardinal process of some gerontic specimens is trilobed.

Subfamily PROKOPINAE Wright, 1965

Prokopia Havlíček, 1953

Type species. By original designation of Havlíček (1953: 6); *Prokopia bouskai* Havlíček, 1953;

Pragian Dvorce-Prokop Limestone, Barrandov, Czech Republic.

Prokopia hillae (Chatterton, 1973)

Fig. 9J-R

Muriferella hillae sp. nov. Chatterton 1973: 28, pl. 3, figs 1–9, 11–15; pl. 35, figs 4, 5.

Prokopia hillae-Lenz & Johnson 1985a: 53, pl. 3, figs 1–12.

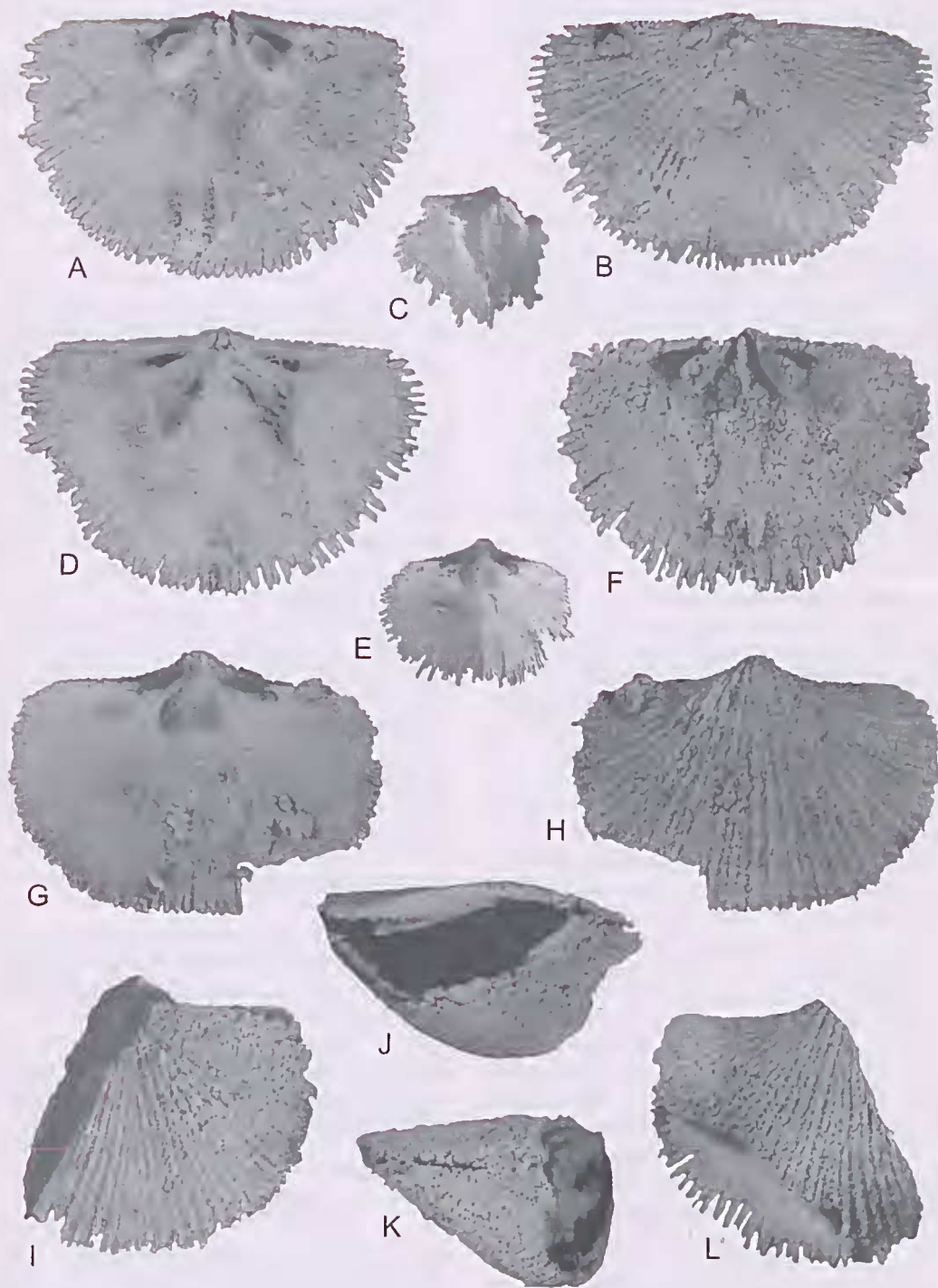
Material. Figured material: AM F117268 (Fig. 9J-L); dorsal valve from ROC 174.1; AM F117269 (Fig. 9M, N); ventral valve from McL 420dh; AM F117270 (Fig. 9O-R); articulated specimen from McL 420dh. Unfigured material: 65 ventral valves, 37 dorsal valves and 12 articulated specimens.

Description. See Chatterton (1973: 28).

Remarks. Following Lenz & Johnson (1985a), *M. hillae* is assigned here to *Prokopia* on the presence of a high triangular median septum in the dorsal valve. Talent et al. (2001), on the other hand, placed this species in synonymy with *M. punctata* (Talent, 1963). However, this synonymy cannot be supported as Johnson & Talent (1967: 44) stated that the median septum of *Muriferella* '...is not high and triangular. All of the specimens investigated show only a slight increase in height of the median septum in the anterior direction.' This statement holds true for all other described species of *Muriferella*.

Some of the specimens assigned to *P. hillae* from the Murrindal Limestone, as well as those described by Chatterton (1973: pl. 3, figs 2, 6, 9) from the Emsian Warroo Limestone Member of the Taemas Limestone at Taemas, differ from Havlíček's (1953) diagnosis for *Prokopia* in possessing fuleral plates (Fig. 9L). Whereas Lenz & Johnson (1985a) made no mention of fuleral plates in their description of *P. hillae* from the Pragian Garra Limestone at Wellington, their figured specimens (pl. 3, figs 1–12) appear to lack them. Although fuleral plates are more characteristic of *M. punctata* than *P. hillae*, they are an unreliable taxonomic feature as their presence varies with the age and size of the individual (Baneroff 1945; Broek pers. comm. 2000).

Fig. 11. *Bidigitus murrindalensis* gen. et sp. nov. All specimens x 8. A, B, holotype, dorsal valve interior and exterior, ROC 159, AM F117279. C, dorsal valve interior, ROC 174.1, AM F126354. D, dorsal valve interior, ROC 159, AM F117280. E, ventral valve interior, McL 420dh, AM F126355. F, dorsal valve interior, ROC 162, AM F117281. G, H, ventral valve interior and exterior, ROC 174.1, AM F117282. I-L, dorsal, lateral, posterior and ventral views of articulated specimen, ROC 162, AM F117283.



Therefore, the presence or absence of fuleral plates in these specimens cannot be considered sufficiently significant to rule out assignment of this species to *Prokopia*.

Subfamily RESSERELLINAE Walmsley &
Boucot, 1971

Resserella Baneroff, 1928

Type species. By original designation of Baneroff (1928: 54); *Orthis canalis* Sowerby in Murchison, 1839; Early Silurian, Wenlock Shale, Woolhope Inlier, Herefordshire, Wales.

Resserella careyi Chatterton, 1973
Fig. 10A-G

Resserella careyi sp. nov. Chatterton 1973: 23, pl. 3, figs 10, 16-27.

Curranella careyi gen. et sp. nov. Chatterton 1973: pl. 35, figs 1-3.

Material. Figured material: AM F117271 (Fig. 10A, B) ventral valve from ROC 162; AM F117272 (Fig. 10C, D) dorsal valve from ROC 162; AM F126351 (Fig. 10E): ventral valve from ROC 159; AM F126352 (Fig. 10F): dorsal valve from ROC 159. Unfigured material: 601 ventral valves, 344 dorsal valves and 185 articulated specimens.

Description. See Chatterton (1973: 23).

Remarks. Chatterton (1973: 25) noted that *R. careyi* is unusual amongst *Resserella*, as diagnosed by Walmsley & Boucot (1971: 494), in possessing teeth and sockets that lack crenulations. However, the teeth of *R. springfieldensis* (Foerste, 1917) from the Wenlock Cedarville Dolomite of Ohio, were described by Walmsley & Boucot (1971: 513) as smooth. The ventral valve muscle field of *R. careyi* is largely confined to the delthyrial cavity and is chordate in juvenile to adult specimens (Fig. 10E-G), as seen in other *Resserella* species such as *R. basalis* (Dalman, 1828) and *R. elongata* (Dalman, 1828) (Walmsley & Boucot 1971). The ventral valve muscle field of gerontic specimens of *R. careyi* though is subtriangular to subpentagonal in outline (Fig. 10A). The *vascula media* of *R. careyi*, as illustrated by Chatterton (1973: pl. 3, figs 25, 27), are subparallel in both valves, a feature Walmsley & Boucot (1971) regard as diagnostic of *Resserella*. The primary difference be-

tween *R. careyi* and other *Resserella* is the symmetrical pattern of branching costellae in the medial region of the dorsal valve (Fig. 10D, F). In contrast, *Resserella* typically displays a pattern of asymmetrically bifurcating costellae in the medial region of the dorsal valve (Walmsley & Boucot 1971).

Some of the Murrindal specimens differ from Chatterton's (1973: 23) original description of *R. careyi* in possessing a short, but broad median ridge in the ventral valve located immediately anterior of the muscle field and disappearing by valve midlength (Fig. 10A). *Resserella logansportensis* Walmsley & Boucot, 1971 from the Pridoli Kenneth Limestone of Indiana and *R. triangularis* (Maurer, 1889) from the Emsian of the Rhineland, both possess a median ridge, but it is much thinner in *R. triangularis* and does not increase in height anteriorly as in *R. logansportensis*. The dorsal valve median ridge of *R. careyi* also occasionally extends beyond the anterior margin of the diductor scars, a feature also occurring in *R. springfieldensis*. As these features tend only to occur in larger specimens, it is concluded they are characteristic of gerontic individuals.

Chatterton (1973: pl. 35, figs 1-3) figured several specimens under the name *Curranella careyi* gen. et sp. nov., despite referring to them as paratypes of *R. careyi* in the text. Strusz (1990: 9) determined this taxon is valid under ICZN Articles 13b and 68d, but as Chatterton (1973) obviously changed the generic placement of *C. careyi*, it can be considered a synonym of *R. careyi* (Strusz 1990).

Subfamily BIDIGITINAE subfam. nov.

Diagnosis. A dalmanellid with a dorsal valve median ridge bifurcating anteriorly into two finger-like projections, that may be raised unsupported above valve floor.

Type genus. By original designation herein; *Bidigitus* gen. nov.; Early Emsian of the Murrindal Limestone, Buchan Group, Buchan, Victoria, Australia.

Bidigitus gen. nov.

Type species. By original designation herein; *Bidigitus murrindalensis* sp. nov.; Emsian of the Murrindal Limestone, Buchan Group, Buchan, Victoria, Australia.

Etymology. L., *bi*, two; L., *digitus*, finger, in reference to the two finger-like projections of the bifurcating median ridge in the dorsal valve.

Type locality and horizon. ROC section (sample ROC 159), early Emsian (*perbonus* Zone), Murrindal Limestone, Buchan Group, Buchan, Victoria, Australia.

Diagnosis. As for subfamily by monotypy.

***Bidigitus murrindalensis* sp. nov.**

Fig. 11A-L

Etymology. Named after the Murrindal Limestone from which this species was recovered.

Diagnosis. As for genus by monotypy.

Type material. Holotype: AM F117279 (Fig. 11A, B); holotype, dorsal valve from ROC 159. Figured paratypes: AM F126354 (Fig. 11C); dorsal valve from 174.1; AM F117280 (Fig. 11D); dorsal valve from ROC 159; AM F126355 (Fig. 11E); ventral valve from McL 420dh; AM F117281 (Fig. 11F); dorsal valve from ROC 162; AM F117282 (Fig. 11G, H); ventral valve from ROC 174.1; AM F117283 (Figs 11I-L); articulated specimen from ROC 162. Unfigured paratypes: 81 ventral valves, 33 dorsal valves and two articulated specimens.

Description. Planoconvex, subcircular to transversely suboval in outline. Width and length approximately equal. Greatest width occurring at, or slightly forward of, hinge line. Cardinal extremities rounded. Ventral valve with weak fold, but median portion more strongly convex than lateral slopes. Dorsal valve with weak, anteriorly widening, sulcus. Anterior commissure weakly unisulcate. Ornament finely parvicostellate.

Ventral valve interarea triangular, apsaeline and incurved. Delthyrium broadly triangular, enclosing an angle of 90° that may be blocked apically by secondary shell material and laterally by narrow deltidial plates. Dorsal valve interarea low, elongately triangular and anaeline to almost eataeline. Interarea interrupted medially by a triangular notothyrium.

Ventral valve interior with deep delthyrial cavity. Non-erentulate, triangular teeth extend down to valve floor or supported by short, stout dental plates. Small, nonstriate crural fossettes impressed on sides of teeth. Shallow to deep lateral cavities present between teeth or dental plates and valve wall. Muscle

field chordate, largely confined to delthyrial cavity, with gently areuate anterior margin. Diductor and adductor muscle scars not well differentiated. Diductors appear to extend further forward than, but do not completely enclose, adductors. Adductor scars broader than diductor scars. Muscle field may be elevated slightly relative to valve floor. Inner surface smooth, apart from crenulated margins.

Dorsal valve interior with posteriorly bilobed cardinal process and myophore. Shaft of cardinal process joins narrow, posteriorly grooved, median ridge. Median ridge low, broad, dividing muscle field. Median ridge bifurcating slightly posterior of anterior margin of muscle field into two finger-like projections extending beyond anterior margin of muscle field, and may be raised, unsupported above valve floor. Brachiophores thickened, rod-like and diverge at 85°. Brachiophore plates continue forward as low muscle bounding ridges laterally, fading away anteriorly. Sockets excavated in valve floor and lacking fulcral plates. Muscle field subtriangular, narrowing anteriorly and not obviously divided into posterior and anterior pairs of adductor scars. Inner surface punctate with crenulated margins.

Measurements. Dimensions are shown in Fig. 12. Average ventral valve width 5.59 mm, length 4.32 mm. Average dorsal valve width 8.9 mm, length is 6.2 mm.

Remarks. *Bidigitus* is assigned to the new subfamily, Bidigitinae, within the Dalmanellidae based on its weakly ventribiconvex to planoconvex profile, chordate ventral valve muscle field that is largely

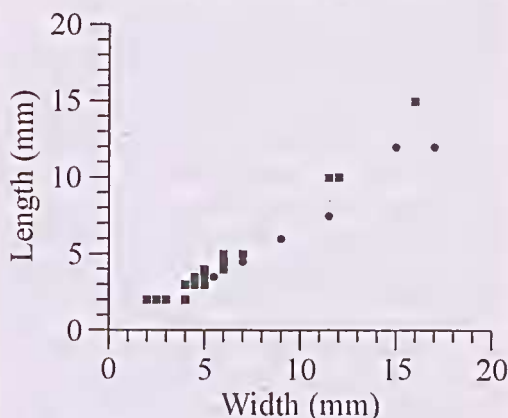


Fig. 12. Dimensions for *Bidigitus murrindalensis* gen. et sp. nov. Length vs width of ■ ventral ($n = 28$) and ● dorsal valves ($n = 10$).

confined to the delthyrial cavity and diductor scars that do not enclose the adductor scars (Fig. 11E). In the dorsal valve simple rod-like brachiophores are supported by brachiophore plates and fulcral plates are absent (Fig. 11A, C). *Bidigitus* is distinguished from all other dalmanellid subfamilies by a dorsal valve median ridge that bifurcates anteriorly into two finger-like projections, that in some specimens stand free of the valve floor (Fig. 11I).

The finger-like projections of the median ridge of *B. murrindalensis* probably functioned as accessory lophophore supports to the brachiophores. An analogous structure can be observed in the species of the acrotretid, *Acrotretella*, such as *A. goldapiensis* Biernat & Harper, 1999 and *A. triseptata* Mergl, 2001. In addition to the median septum, these species also possess lateral accessory septa, providing extra support for the lophophore.

Bidigitus murrindalensis has a stratigraphic range extending throughout the ROC section of the Murrindal Limestone, but only occurs in the lower sampled horizons of the McL section (Tables 1, 2). Talent (pers. comm. 2000) however, has indicated that *B. murrindalensis* also occurs in latest Pragian to early Emsian Buchan Caves Limestone.

Ontogeny. Neanic *B. murrindalensis* recovered are all incomplete. The shells are ventri-biconvex with a deep, broad sulcus in the dorsal valve, whereas the ventral valve is evenly convex. The triangular ventral valve interarea is steeply anacline and is flat or slightly curved. The delthyrium is blocked laterally by small deltidial plates, which may or may not join together posteriorly to block the apex of the delthyrium (Fig. 10F). The dorsal valve interarea is flat and anacline. Internally, the ventral valve possesses a deep delthyrial cavity to which the cordate to subtriangular muscle field is largely confined. The teeth are strongly developed, triangular in cross section and fused directly to the valve wall. Some specimens possess faintly impressed crural fossettes. Lateral cavities developed as shallow depressions only (Fig. 10F). The dorsal valve possesses long flattened brachiophores supported by variably developed brachiophore plates that continue forward as faint muscle bounding ridges. The cardinal process occurs as a simple, unlobed ridge, continuous with the broad, low median ridge, which bears a groove extending along its length. The two thin, finger-like bifurcations of the median ridge are raised, unsupported above the valve floor. The muscle-field is subtriangular and not obviously quadripartite. The

triangular sockets, variably raised on secondary shell material, are covered posteriorly by the dorsal valve interarea (Fig. 10C).

Juvenile specimens of *B. murrindalensis* possess features intermediate between those of earlier and later growth stages. An apparent exception to this is the presence of a weakly developed fold, or even a keel, in the ventral valve of some specimens. Such a feature is not seen in other growth stages. In addition, punctae are clearly visible in both valves of juvenile specimens.

Sub-adult to adult specimens of *B. murrindalensis* are planoconvex, the dorsal valve sulcus having become indistinct (Fig. 10J, K). Internally, the muscle fields of both valves are more firmly impressed and the ventral valve muscle field is largely confined to the delthyrial cavity and has an elevated anterior margin. The teeth are strong, robust and supported in some specimens by short, stout dental plates with strongly impressed crural fossettes. Lateral cavities well developed and distinct (Fig. 11G). The dorsal valve muscle field is bounded by thicker ridges and is elevated above the valve floor. The cardinal process is bilobed in all specimens. The brachiophores are thickened and the sockets of all adult specimens are raised on secondary shell material. The groove on the median ridge is indistinct, particularly posteriorly. The bifurcating prongs of the median ridge are fused to the valve floor throughout their length in most specimens (Fig. 11A, D, F).

The only gerontic specimens recovered are two dorsal valves. These are both flat, with only the faintest trace of a sulcus. Internally, these specimens differ most notably from adult specimens in possessing a prominent bilobed to trilobed cardinal process that fills the notothyrium.

Family MYSTROPHORIDAE Schuchert & Cooper, 1931

Biernatium Havlíček, 1975

Type species. By original designation of Havlíček (1975: 234); *Skenidium fallax* Gürich, 1896; Givétian of the Celechovice na Hlane (upper 'red' horizon) of Moravia.

Remarks. Biernat (1959) placed *B. fallax* in synonymy with *Kayserella lepida* (Schnur, 1853) as she considered the internal features of the dorsal valves identical. This assessment cannot be supported as the cruralium of *B. fallax* is long, narrow and

extends almost to the anterior margin (Havlíček 1977), whereas the eruralium of *Kayersella* Hall & Clarke, 1892 is restricted to the posterior portion of the valve (Biernat 1959). *Mystrophora* Kayser, 1871, unlike *Biernatium*, possesses a median ridge in the ventral valve (Havlíček 1977; Harper 2000). *Planicardinia* Savage, 1968 from the Lochkovian tongue of Garra Limestone at Manildra, in contrast to *Biernatium*, possesses a vertical, spoon-shaped eruralium. Members of the Protorthida possessing a eruralium, like *Skenidioides* Schuchert & Cooper, 1931, differ from *Biernatium* in possessing an open delthyrium, a free spondylium and are impunctate (Williams & Harper 2000).

***Biernatium catastum* sp. nov.**

Fig. 10H-M

Etymology. *L. catasta*, stage, platform, scaffold; in reference to the diamond-shaped eruralium.

Diagnosis. *Biernatium* with an elongate, diamond-shaped eruralium in the dorsal valve.

Type material. Holotype: AM F117274 (Fig. 10H-J): dorsal valve from MeL 520. Figured paratypes: AM F117273 (Fig. 10K): ventral valve from MeL 520; AM F117275 (Fig. 10L, M): dorsal valve from MeL 520. Unfigured paratypes: 12 ventral valves, 18 dorsal valves and one articulated specimen.

Type horizon and locality. MeL section (sample MeL 520), Emsian (*perbomus* Zone), Murrindal Limestone, Buchan Group, Buchan, Victoria, Australia.

Description. Ventribiconvex shells, transversely suboval in outline. Length tending to be slightly greater than width. Cardinal extremities rounded right angles. Maximum width occurring at, or slightly posterior of, midlength. Ventral valve subpyramidal, occasionally with a weakly developed fold. Dorsal valve weakly convex with well-developed sulcus extending from beak to anterior margin, becoming broader and deeper anteriorly. Base of sulcus angular. Anterior commissure unisulcate. Ornament of subangular costae and occasional growth lines.

Ventral valve interarea triangular, steeply apsaeline to almost catacline and slightly curved. Delthyrium triangular, higher than wide, enclosing angle of 70°. Delthyrium restricted apically by

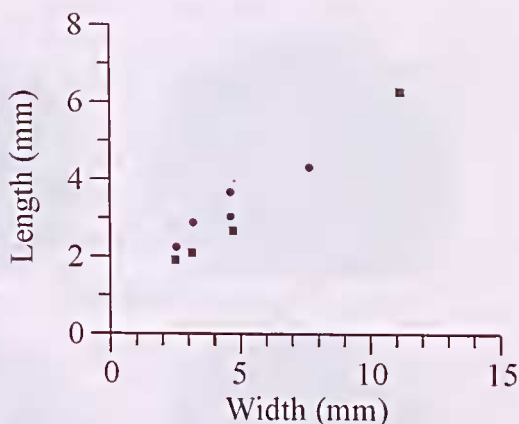
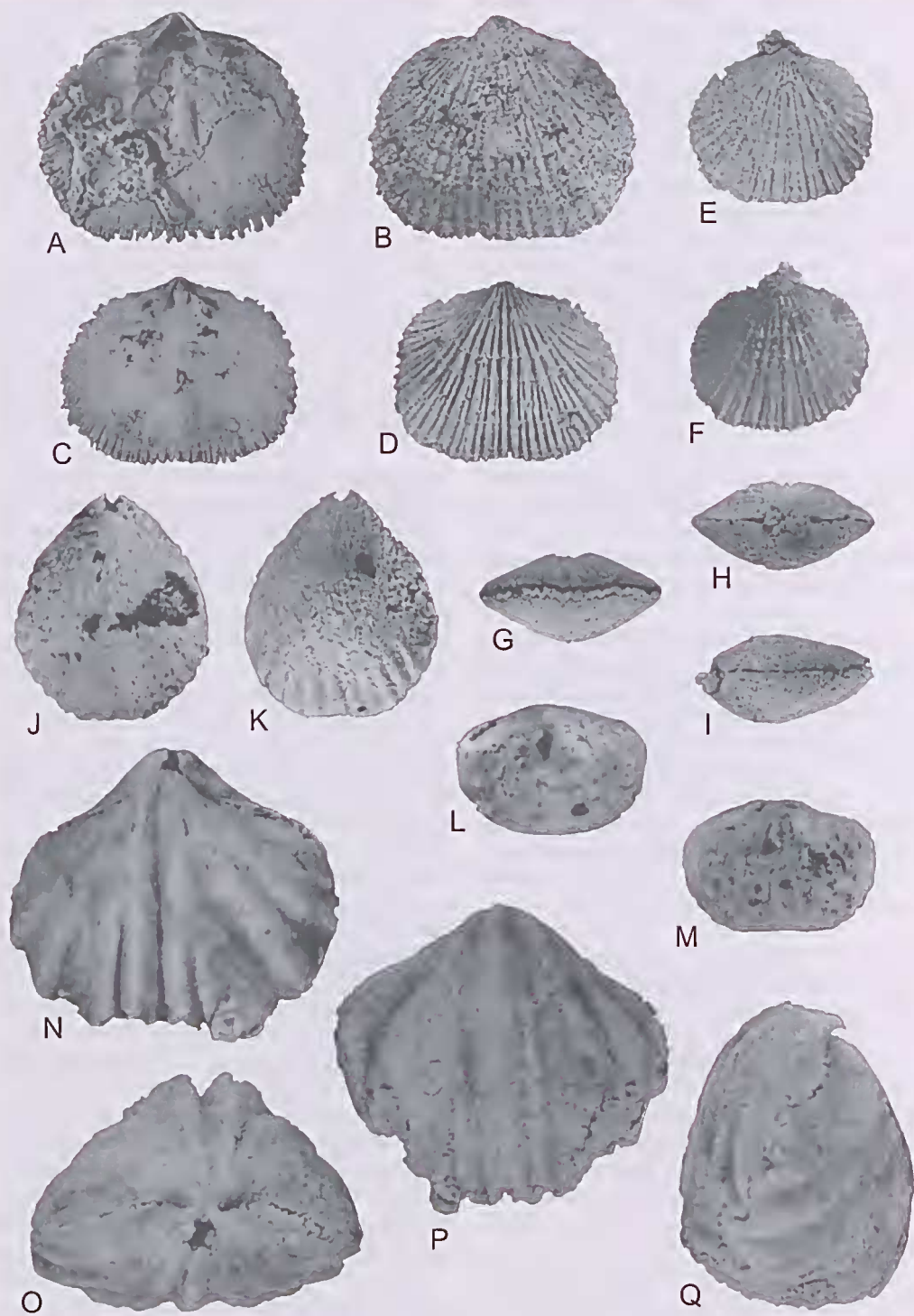


Fig. 13. Dimensions for *Biernatium catastum* sp. nov. Length vs width of ■ ventral ($n = 4$) and ● dorsal valves ($n = 5$).

minute plate and laterally by thin deltidial plates. Dorsal valve interarea triangular, wider than high, steeply anacline and flat. Notothyrium broadly triangular and blocked apically by cardinal process.

Ventral valve interior with deep delthyrial cavity. Teeth flat, triangular and supported by recessive, subparallel dental plates. Muscle field subtriangular and confined largely to posterior half of delthyrial cavity. Anterior margin of muscle field gently arcuate and raised above valve floor. Diductor sears slightly longer than adductor sears, but do not enclose adductors anteriorly. Adductor sears broader than diductors. Inner surface finely erenulate with a suggestion of punctation.

Dorsal valve interior with thickened, ridge-like cardinal process (bilobed in one specimen) with myophore and shaft continuous with median septum. Sockets shallow, raised above valve floor on secondary shell material, lacking fulcral plates. Interarea covers posterior portion of sockets. Median septum thin, triangular in side view, reaching maximum height close to anterior margin and ending at anterior margin. Brachioophores long, triangularly pointed and divergent at 110°. Thin brachioophore plates convergent onto median septum, forming a diamond-shaped eruralium extending at least to valve midlength. Cruralium deeply concave and attached to valve floor posteriorly, rising anteriorly at 30°, becoming shallower as its height increases. Cruralium divided into four fields by median septum and two low, rounded and indistinct ridges, convergent towards cardinal process. Inner surface punctate and marked, at least marginally, by fine crenulations.



Measurements. Dimensions are shown in Fig. 13. Average ventral valve width 5.44 mm, length 3.2 mm. Average dorsal valve width 4.96 mm, length 3.23 mm.

Remarks. *Biernatium catastum* differs from *B. fallax* from the Givetian shales of the Grzegorzowiec-Skaly section of the Holy Cross Mountains of Poland (Havlíček 1977), Givetian of the Celechovice na Hanc (upper 'red' horizon) of Moravia (Fiehn & Havlíček 1978) and questionably from the Eifelian of Padaukpin (Northern Shan States), Burma (Havlíček 1975, 1977), primarily on features of the cruralium. The cruralium of *B. fallax* arises from widely divergent brachioophores situated subparallel to the hinge line, making the cruralium triangular in shape and much narrower anteriorly than the cruralium of *B. catastum*. The cruralium of *B. fallax* also possesses a weak undulation at its midpoint that, according to Havlíček (1977), resembles the quadripartite condition of the cruralium of *Mystrophora areola* (Quenstedt, 1871). *Biernatium catastum* lacks this feature (Fig. 10H, I, L). In addition, the outline of *B. fallax*, which is semi-oval or semi-circular, differs from the transversely suboval outline of *B. catastum*.

The Murrindal specimens appear most closely related to *B. simplicior* (Barrande, 1879) from the Pragian Koneprusy Limestone of the Czech Republic (Havlíček 1977). Both possess a long cruralium, a high, triangular median septum and a delthyrium blocked laterally by thin deltidial plates and apically by a tiny plate (Fig. 10J). However, according to the diagnosis given by Havlíček (1977: 208), the cruralium of *B. simplicior*, like the cruralium of *B. fallax*, appears to be triangular in shape, suggesting that the brachioophores of *B. simplicior* are more widely divergent than those of *B. catastum*. Direct comparisons, however, are not possible as neither Barrande (1879) nor Havlíček (1977) illustrated the dorsal valve interior of *B. simplicior*.

Kaysarella emanuelensis Veevers, 1959, from the Frasnian of the Fitzroy Basin of Western Australia, is reassigned herein to *Biernatium* following Havlíček (1977), on the basis that the cruralium extends almost to the anterior margin. However, the cruralium of *B. emanuelensis* differs markedly from other members of this genus in remaining narrow

throughout its length and possessing undulating, rather than straight edges. In addition, the median septum of *B. emanuelensis* reaches its highest point around valve midlength, whereas in *B. catastum* this feature occurs closer to the anterior margin (Fig. 10I, L).

Family RHIPIDOMELLIDAE Schuchert, 1913
Subfamily RHIPIDOMELLINAE Schuchert, 1913

Aulacella Schuchert & Cooper, 1931

Type species. By original designation of Schuchert & Cooper (1931: 246); *Orthis eifliensis* Schnur, 1853; Eifelian of the 'Kalk' of the Eifel, Germany.

Aulacella philipi Chatterton, 1973

Fig. 14A-I

Aulacella philipi sp. nov. Chatterton 1973: 31, pl. 4, figs 13–20; pl. 5, figs 9–15; pl. 35, figs 10, 11.—Broek & Talent 1993: 233, fig. 10A–O.

Aulacella stoermeri sp. nov. Chatterton 1973: 34, pl. 4, figs 1–12; pl. 5, figs 1–8.

Material. Figured material: AM F117284 (Fig. 14A, B): ventral valve from McL 420dh; AM F117285 (Fig. 14C, D): dorsal valve from McL 420dh; AM F117286 (Fig. 14E–I): articulated specimen from ROC 165. Unfigured material: 56 ventral valves, 91 dorsal valves and eight articulated specimens.

Description. See Chatterton (1973: 31).

Remarks. Chatterton (1973) described two new species of *Aulacella*, *A. philipi* and *A. stoermeri* from the Emsian 'Receptaenulites' and Warroo Limestone Members of the Taemas Limestone at Taemas. He differentiated between them on slight differences in the position of maximum width, length of the hinge line compared to maximum width, degree of flabellation of the diductor scars and the amount of scalloping of the lateral muscle bounding ridges in the muscle field of the ventral valve. However, Chatterton (1973: 34) and Broek & Talent (1993: 233) noted that considerable variation occurs in many features of *A. philipi*. Therefore, these differences

Fig. 14. A–I, *Aulacella philipi* Chatterton, 1973. All specimens $\times 3$. A, B, ventral valve interior and exterior, McL 420dh, AM F117284. C, D, dorsal valve interior and exterior, McL 420dh, AM F117285. E–I, dorsal, ventral, anterior, posterior and lateral views of articulated specimen, ROC 165, AM F117286. J–M, *Eoglossinotoechia linki* Chatterton, 1973, ventral, dorsal, posterior and anterior views of articulated specimen, ROC 162, AM F117287, $\times 7$. N–Q, '*Pugnax*' *oepiki* Chatterton, 1973. N–Q, dorsal, posterior, ventral and lateral views of articulated specimen, McL 417, AFM117288, $\times 4$.

are considered to fall within the range of intraspecific variation.

Chatterton (1973) and Broek & Talent (1993) believed *A. philipi* to be closely related to the type species, *A. eifliensis* from the Eifelian of Germany and Poland. Chatterton (1973) separated these two species on the basis that *A. philipi* has less rounded costellae and smaller brachiophore plates and teeth. However, given the considerable level of intraspecific variation displayed by *A. philipi*, Chatterton (1973: 34) stated that it was difficult to separate the two species on other characteristics. Broek & Talent (1993) believed these variations may not be significant at the species level and that *A. philipi* could be a junior synonym of *A. eifliensis*. However, comparisons between the two species are difficult due to the considerable level of intraspecific variation displayed.

Order RHYNCHONELLIDA Khun, 1949

Superfamily UNCINULOIDEA Rzhonsnitskaya, 1956

Family GLOSSINOTOECHIIDAE Havlíček, 1992

Eoglossinotoechia Havlíček, 1959a

Type species. By original designation of Havlíček (1959a: 81); *Eoglossinotoechia cacuminata* Havlíček, 1959a; late Loehkovian-Pragian of the Slivence Limestone, Dvorce, Czech Republic.

Eoglossinotoechia linki Chatterton, 1973

Fig. 14J-M

Eoglossinotoechia linki sp. nov. Chatterton 1973: 120, pl. 31, figs 1–22, 27.–Xu 1987: 38, pl. 3, fig. 21.

Material. Figured material: AM F117287 (Fig. 14J-M); articulated specimen from ROC 162. Unfigured material: 14 articulated specimens.

Description. See Chatterton (1973: 120).

Remarks. The specimens assigned to *E. linki* from the Murrindal Limestone closely resemble those recovered by Chatterton (1973) from the Emsian 'Receptaculites' Limestone Member at Taemas. However, as only articulated specimens have been recovered from the Murrindal Limestone, a comparison of internal features is not possible. The Murrindal specimens differ most notably though from those described by Chatterton (1973) in being

smaller (Fig. 15), but only four of the specimens recovered were complete enough to obtain accurate dimensions. The Murrindal specimens also possess less pronounced costae, most likely related to their smaller size.

Eoglossinotoechia linki has also documented by Xu (1987) from the Pragian Daredong Formation of China. The single specimen figured by Xu (1987: pl. 3, fig. 21) has 21 plications developed along the anterior and lateral margins, and falls within the range of 20 to 28 plications established by Chatterton (1973) for mature specimens of *E. linki*. Like *E. linki* from the 'Receptaculites' Limestone Member, those from the Daredong Formation are larger than the Murrindal specimens (Fig. 15).

Eoglossinotoechia linki differs from *E. cacuminata* from the Silurian and Lower Devonian of the Czech Republic (Havlíček 1959a), in possessing fewer and more prominent costae, a less convex ventral valve and a more obviously bilobate cardinal process. Other *Eoglossinotoechia* from the same area, such as *E. mystica* Havlíček, 1959a and *E. sylphidea* (Barrande, 1847), possess fewer and less well-developed costae than *E. linki*. None of the Devonian species of *Eoglossinotoechia* reported

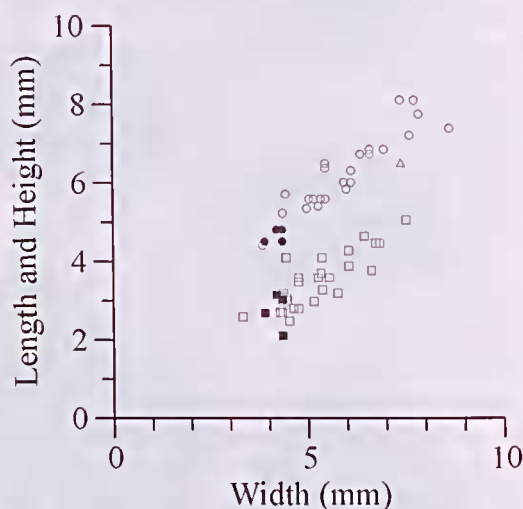


Fig. 15. Comparison of *Eoglossinotoechia linki* from the Emsian 'Receptaculites' Limestone Member at Taemas (average width 16.7 mm; length 6.33 mm; height 4.07 mm) (Chatterton 1973: fig. 40), with *E. linki* from the Murrindal Limestone (average width 4.2 mm; length 4.65 mm; height 2.81 mm) and *E. linki* from the Pragian Daredong Formation of China (Xu 1987: pl. 3, fig. 21). Length vs width of ● Murrindal ($n = 4$), ○ Taemas ($n = 24$) and △ Daredong specimens ($n = 1$). Height vs width of ■ Murrindal ($n = 4$) and □ Taemas specimens ($n = 27$).

from Morocco by Drot (1964) appears closely related to *E. linki* (Chatterton 1973).

Chatterton's (1973) report of *E. linki* from Tasmania was the first recorded occurrence of this genus in Australia. Since then, only one additional species of *Eoglossinotoechia* has been reported from Australia, *E. catombalensis* Lenz & Johnson, 1985b from the Pragian Garra Limestone at Wellington (Lenz & Johnson 1985b) and the Lochkovian Garra Limestone at Eurimbla (Brock 2003b) possesses fewer (12 to 18) and more rounded costae that are developed over the entire shell. The costae of *E. linki*, on the other hand, are flatter, more numerous (20 to 28) and only developed marginally. The ventral valve muscle field of *E. catombalensis* is subtriangular in outline, weakly impressed and divided by a prominent median ridge, whereas the ventral valve muscle field of *E. linki* is more variable in outline, strongly impressed and is not divided by a median ridge. In addition, the dorsal valve of *E. linki* contains a septalium, which is not developed in *E. catombalensis*.

Superfamily PUGNACOIDEA Rzhonsnitskaya, 1956

Family PUGNACIDAE Rzhonsnitskaya, 1956

Pugnax Hall & Clarke, 1893

Type species. By subsequent designation of ICZN Opinion 420 (1956: 134); *Terebratula acuminata* Sowerby, 1822; Visnean subzone D2, Dernyshire, Thorpe Cloud, England.

'**Pugnax**' *oepiki* Chatterton, 1973
Figs 14N-Q, 16A-I

'*Pugnax*' *oepiki* Chatterton 1973: 123, pl. 32, figs 25–41.

Material. Figured material: AM F117288 (Figs 14N-Q; 16I): articulated specimen from MeL 417; AM F117289 (Fig. 16A): articulated specimen from ROC 162; AM F117290 (Fig. 16B): articulated specimen from ROC 162; AM F117291 (Fig. 16C): articulated specimen from ROC 162; AM F117292 (Fig. 16D): articulated specimen from ROC 162; AM F117293 (Fig. 16E): articulated specimen from ROC 162; AM F117294 (Fig. 16F): articulated specimen from ROC 162; AM F117295 (Fig. 16G): articulated specimen from ROC 162; AM F117296 (Fig. 16H): articulated specimen from ROC 165; AM F117288 (Fig. 16I): articulated specimen from MeL 417. Unfigured mate-

rial: 11 ventral valve fragments, two dorsal valve fragments and 36 articulated specimens.

Description. See Chatterton (1973: 123).

Remarks. Chatterton (1973) questionably assigned this species to *Pugnax* on the basis of a few dorsal valve interiors showing that the erural bases are extended dorsally, fused with the valve floor, and do not converge towards a median septum to form a septalium. Chatterton (1973: 125) also noted this species possesses similarities with *Parapugnax*, such as a well-defined fold and sulcus and a ventral valve that is not flat or concave posteriorly. In addition, this species differs from most other pugnacids, including the type species, in possessing a thin, posteriorly perforated hinge plate that unites the erural bases (Chatterton 1973). This suite of characteristics led Talent et al. (2001) to propose that '*P. oepiki*' may represent a new genus of Pugnacidae, but additional dorsal valve interiors are required before a more positive generic identification is possible. None of the specimens recovered from the Murrindal Limestone show any internal structures.

Order SPIRIFERIDA Waagen, 1883

Remarks. The higher level classification used for the Spiriferida herein follows that of Carter et al. (1994).

Suborder SPIRIFERACEA Waagen, 1883
Superfamily CYRTIOIDEA Frederiks, 1924
Family SPINELLIDAE Johnson, 1970
Subfamily SPINELLINAE Johnson, 1970

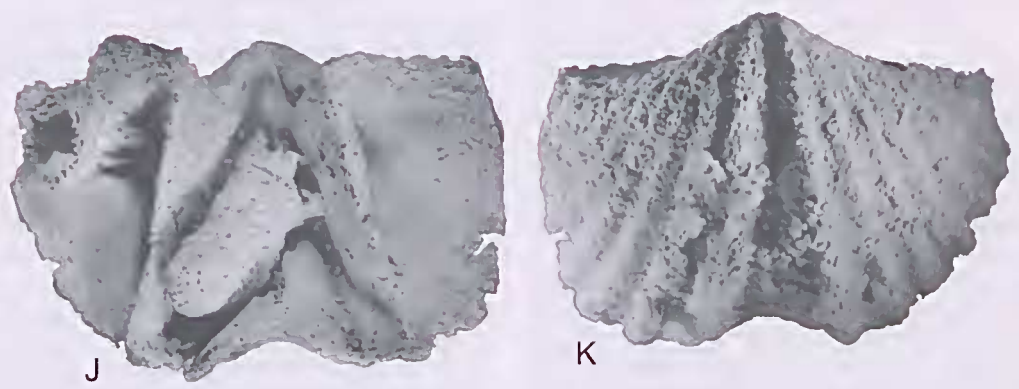
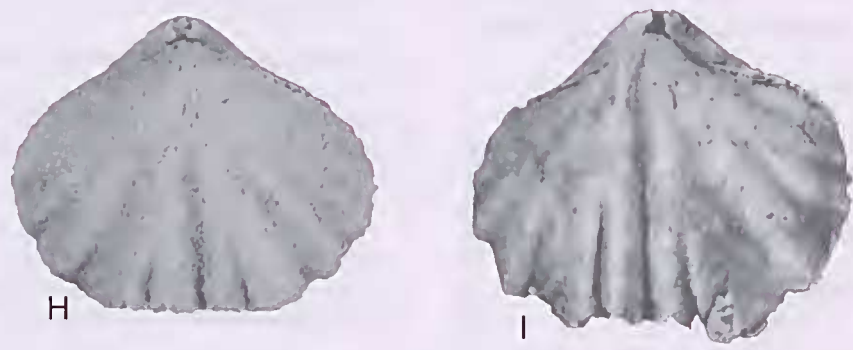
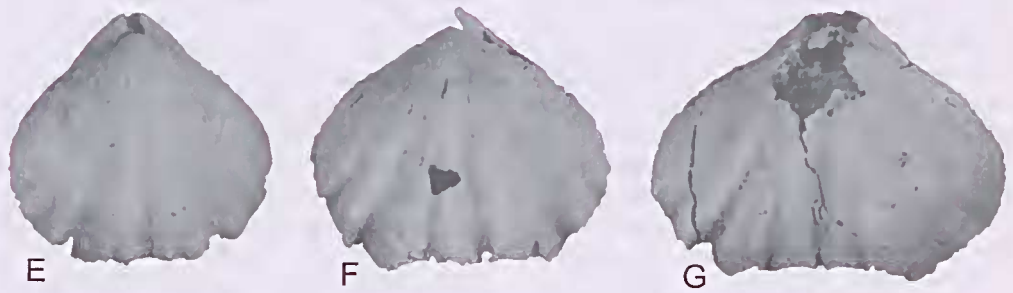
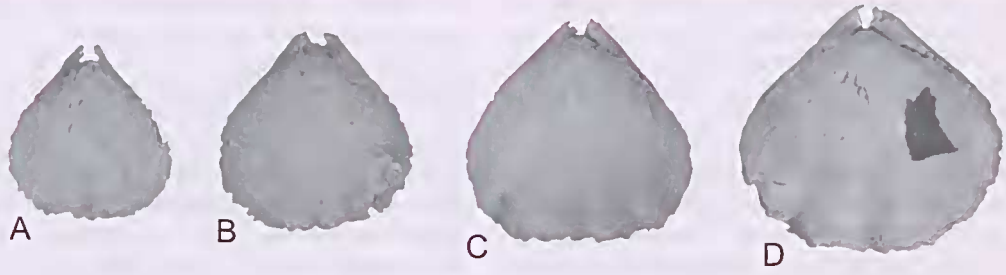
Spinella Talent, 1956a

Type species. By original designation of Talent (1956a: 21); *Spinella buchanensis buchanensis* Talent, 1956a; latest Pragian to early Emsian Buchan Caves Limestone, Buchan Group, Buchan, Victoria, Australia.

Spinella buchanensis buchanensis Talent, 1956a
Figs 16J, K, 17A, B

Spirifer laevicostata-McCoy 1876: pl. 35, figs 2–2b.
Spirifer yassensis-Chapman 1905: 16, pl. 5, figs 2, 3.-
?Chapman 1914: 161, fig. 86E.

Spinella buchanensis sp. nov. Talent 1956a: 22, pl. 1, figs 1–5; pl. 2, figs 5–7.



?*Spinella*? sp. aff. *S. buchanensis*-Talent 1963: 85, pl. 53, figs 7–9.

Material. Figured material: AM F117297 (Fig. 16J, K): ventral valve from ROC 162; AM F117298 (Fig. 17A, B): dorsal valve from ROC 159. Unfigured material: 24 ventral valves, three dorsal valves and one articulated specimen.

Description. See Talent (1956a: 22).

Remarks. Talent (1956a) divided *S. buchanensis* into three new subspecies, *S. b. buchanensis*, *S. b. scissura* and *S. b. philipi* that differ primarily in the number of plications and in the arrangement of spine bases. The Murrindal specimens are conspecific with *S. b. buchanensis*, possessing lateral slopes with 11 to 14 simple plications. No spine bases were observed. In comparison, *S. b. philipi* is more obese, has lateral slopes bearing 13 to 18 simple plications and has a more strongly incurved ventral valve beak. *Spinella buchanensis scissura* is distinguished by lateral slopes with only 10 to 11 plications and by the plications flanking the sinus bearing a median groove (Talent 1956a). In addition, *S. b. buchanensis* is present not only throughout the Buchan Caves Limestone, but also extends up into the overlying Taravale Formation. The other two subspecies have relatively restricted stratigraphic ranges, being confined to the uppermost parts of the Buchan Caves Limestone (Talent 1956a).

Spinella maga Talent, 1956a, also from the Buchan Caves Limestone, possesses a greater number of plications (lateral slopes bear 18 to 20 plications), a more strongly incurved ventral valve beak and a granular surface ornament compared to *S. b. buchanensis*. *Spinella yassensis* (de Koninck, 1876), from Taemas (Chatterton 1973) and the Emsian Lick Hole Formation at Ravine (Strusz et al. 1970), is distinguishable by its smaller size, more elongate shell, higher fold, greater number of plications and a microornament of more elongate spine bases. *Spinella pittmani* (Dun, 1904), from the Emsian Gleninga Formation of the Yarra Yarra Creek Group and the late Pragian to early Emsian Trof's Formation (Dun 1904; Sherwin 1995; Földvary 2000), is similar in size to *S. b. buchanensis*. However, *S. b. buchanensis* is more transverse and has a more rounded sulcus (Sherwin 1995).

Spinella talenti Johnson, 1970a, from the Lower Devonian of Lone Mountain, Nevada, differs primarily in possessing a microornament of radial striae and tends to have flatter plications, but, as noted by both Talent (1956a: 27) and Johnson (1970a: 205), some specimens of *S. b. buchanensis* also have relatively flat plications. Perry (1984) questionably referred a dorsal valve fragment from the Pragian beds of the Delorme Formation to *Spinella*, which he described as being internally very similar to *S. talenti*.

Spinella ineerta (Fuchs in Priestersbaeck & Fuchs, 1909), described by Vandereammen (1963) from the early Emsian of Belgium, appears markedly different from *S. b. buchanensis*. It possesses more numerous and finer plications and a sulcus lacking any costae. The microornament of *S. ineerta* also differs in consisting of subcylindrical spine bases.

Spinella yassensis (de Koninck, 1876) Fig. 17C–G

Spirifer yassensis de Koninck 1876: 104, pl. 3, fig. 6–6b.-de Koninck 1898: 83, pl. 3, fig. 6–6b.-Sussmilch 1914: fig. 23, 6–6b.-Sussmilch 1922: fig. 23, 6–6b.

Spirifer latisinuatus de Koninck 1876: 105, pl. 3, fig. 7–7b.-de Koninck 1898: 84, pl. 3, fig. 7–7b.

Spinella yassensis yassensis-Strusz, Chatterton & Flood 1970: 176, pl. 7, figs 1–14; pl. 8, figs 1–3, 7, 9–10; pl. 9, fig. 16.

Spinella yassensis ravinia n. subsp. Flood (in Strusz, Chatterton & Flood 1970): 179, pl. 9, figs 1–14, 17.

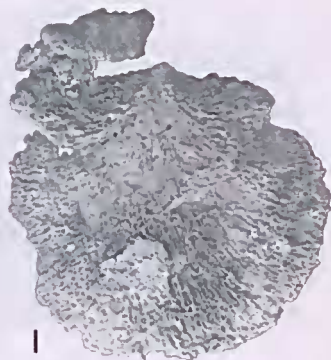
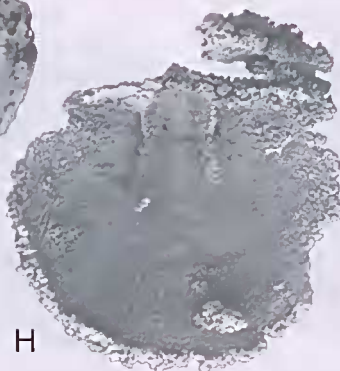
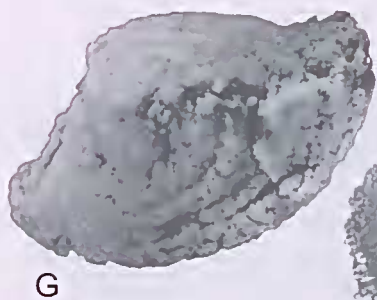
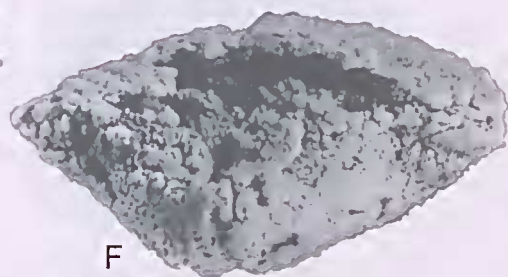
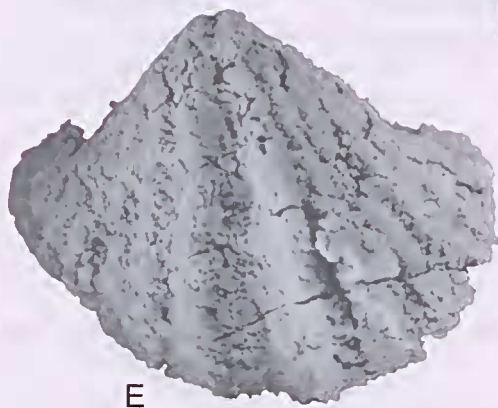
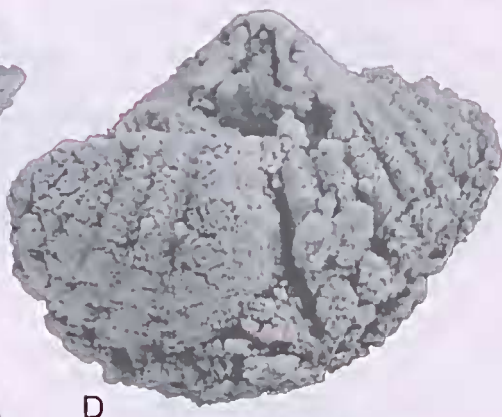
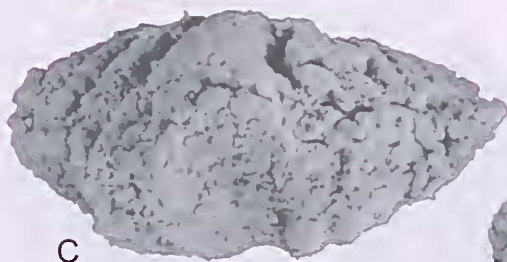
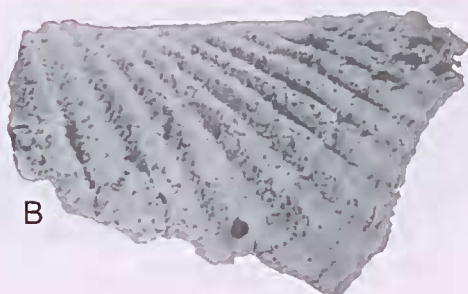
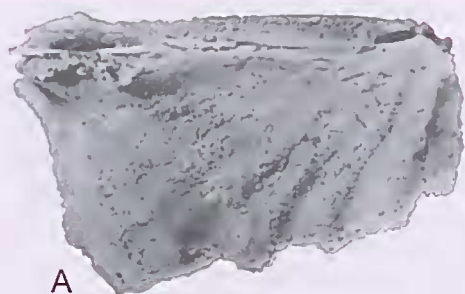
Spinella yassensis, n. subsp? Strusz, Chatterton & Flood 1970: 181, pl. 8, figs 4–6, 8.

Spinella yassensis-Chatterton 1973: 105, pl. 26, figs 1–13; pl. 30, figs 16–20.

Material. Figured material: AM F117299 (Fig. 17C–G): articulated specimen from ROC 165. Unfigured material: one ventral valve.

Remarks. Flood (in Strusz et al. 1970) erected the new subspecies, *S. y. ravinia*, which was defined as having a significantly shallower shell with a narrower and flatter fold and a slightly higher number of plications than *S. y. yassensis*. Following Talent et

Fig. 16. A–I, '*Pugnax*' *oepiki* Chatterton, 1973. All specimens x 4. All dorsal views of articulated specimens. A–G, ROC 162, AM F117289–117295. H, ROC 165, AM F117296. I, McL 417, AM F117288. J, K, *Spinella buchanensis buchanensis* Talent, 1956a, ventral valve interior and exterior, ROC 162, AM F117297, x 3.



al. (2001), however, these differences are not considered great enough to warrant their separation from *S. y. yassensis*.

Strusz et al. (1970) also documented *Spinella yassensis* n. subsp? from the base of the Emsian 'Receptaculites' Limestone Member at Taemas. It was described as being slightly larger, having a greater variability in shape and the curvature of the ventral valve interarea being less pronounced than *S. y. yassensis*. Statistical comparisons showed significant differences between *S. yassensis* n. subsp? and *S. y. yassensis* in terms of shape and relative width of the fold. However, as pointed out by Strusz et al. (1970: 181), only a handful of specimens were available for study and therefore any differences must be considered inconclusive. Until additional material is obtained designation of the Taemas form of *S. yassensis* as a new subspecies appears unwarranted.

Spinella yassensis differs from *S. buchaneensis* in being smaller, more elongate, possessing a higher fold, a greater number of plications in some larger specimens and a microornament consisting of more elongate spine bases. *Spinella maga* possesses significantly more plications and growth lamellae that are only occasionally developed. *Spinella yassensis* appears very similar to *S. pittmani*, but is smaller and some have a ventral valve muscle field that is radially, rather than longitudinally, striate (Sherwin 1995).

Superfamily AMBOCOELIOIDEA George, 1931

Family AMBOCOELIIDAE George, 1931

Subfamily RHYNCHOSPIRIFERINAE

Paulus, 1957

Ambocoelia Hall, 1860

Type species. By original designation of Hall (1860: 71); *Orthis umbonata* Conrad, 1842; Middle Devonian Hamilton Group, New York, America.

Ambocoelia sp. aff. *A. runnegari*

(Chatterton, 1973)

Figs 17H, I, 18A-C

aff. *Ambothyris runnegari* sp. nov. Chatterton 1973: 99, pl. 19, figs 1-14.

Material. Figured material: AM F117300 (Fig. 17H, I): dorsal valve from MeL 520; AM F117301 (Fig. 18A, B): ventral valve from MeL 520; AM F117302 (Fig 18C): articulated specimen from MeL 520. Unfigured material: 15 ventral valves, 12 dorsal valves and three articulated specimens.

Description. See Chatterton (1973: 99).

Remarks. Chatterton (1973) assigned this species from the Emsian 'Receptaculites' and Warroo Limestone Members of the Taemas Limestone at Taemas to *Ambothyris* George, 1931 as it closely matched Hlavíček's (1959b: 176) diagnosis for *Ambothyris*, only differing in possessing a rod-like plate in the apex of the delthyrium and the crural plates are not united to form a cruralium. Examination of Chatterton's (1973: pl. 19, figs 13, 14) figured material however indicates that crural plates are lacking in *A. runnegari*. As in the Murrindal specimens, the crura appear to be supported by crural bases only, which extend forward for about one third of the shell length (Fig. 17H). Following Carter et al. (1994), this species is therefore reassigned to *Ambocoelia*.

Although closely resembling *A. runnegari* in terms of profile, outline and ornament, the Murrindal specimens differ from Chatterton's (1973) material in possessing more variably developed dorsal and ventral valve sulci and lack the rod-like plate in the apex of the delthyrium (Fig. 18B, C). Only one specimen shows any trace of median ridge in the ventral valve (Fig. 18B). However, as few of the Murrindal specimens are free from secondary infilling, it is not possible to determine the presence or absence of a median ridge in the ventral valve. Comparison of microornament is not possible as none has been preserved in the Murrindal specimens. Alternatively, the Murrindal specimens may represent a new species closely related to *A. runnegari*.

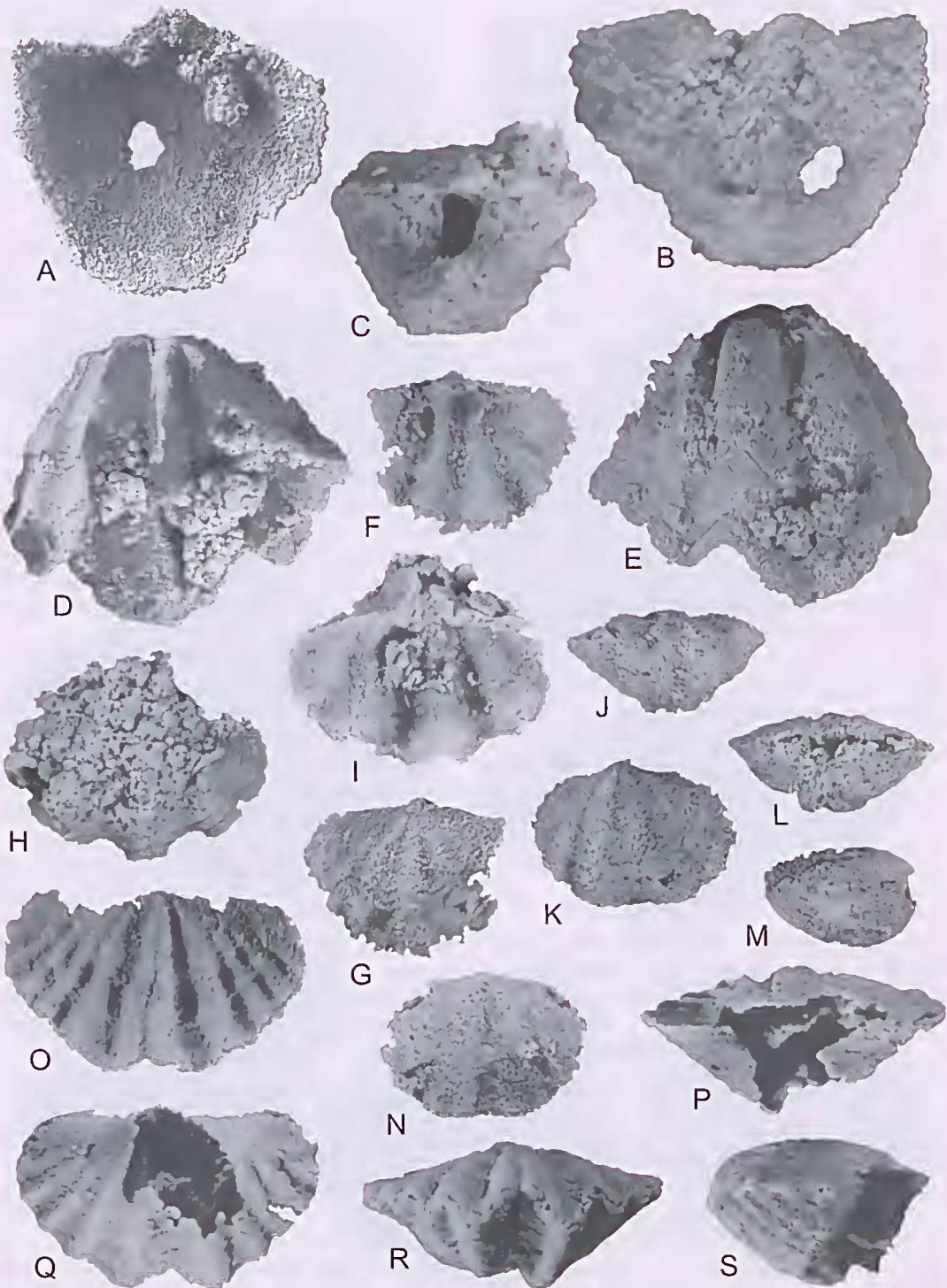
Suborder DELTHYRIDINA Ivanova, 1972

Superfamily DELTHYRIDOIDEA Phillips, 1841

Family DELTHYRIDIDAE Phillips, 1841

Subfamily DELTHYRIDINAE Phillips, 1841

Fig. 17. A, B, *Spinella buchaneensis buchaneensis* Talent, 1956a, dorsal valve interior and exterior, ROC 159, AM F117298, x 3. C-G, *Spinella yassensis* (de Koninck, 1876), anterior, dorsal, ventral, posterior and lateral views of articulated specimen, ROC 165, AM F117299, x 7. H, I, *Ambocoelia* sp. cf. *A. runnegari* (Chatterton, 1973), dorsal valve interior and exterior, MeL 520, AM F117300, x 20.



***Delthyris* Dalman, 1828**

Type species. By original designation of Dalman (1828: 120); *Delthyris elevata* Dalman, 1828; Silurian of Gotland.

***Delthyris?* sp.**

Fig. 18D, E

Material. Figured material: AM F117303 (Fig. 18D); ventral valve from MeL 520. Unfigured material: six ventral valves.

Remarks. The plications of these specimens range from low and rounded to high and subangular, with well-developed growth lines (Fig. 18E). Internally, well-developed dental plates are present in at least one specimen and muscle scar impressions are lacking. These features, and their variability, are all reminiscent of *Cyrtina wellingtonensis* Dun, 1904, which has also been recovered from the Murrindal Limestone. However, these specimens have been tentatively assigned to *Delthyris* on the presence of a median septum in the ventral valve that terminates abruptly around valve midlength (Fig. 18D). In two specimens, the median septum appears to have a serrated anterior margin. These features suggest the affinities of this species lies with *Delthyris hudsoni* Chatterton, 1973, from the Emsian 'Receptaculites' and Warroo Limestone Members of the Taemas Limestone at Taemas. Additional material is required for a more positive identification.

Subfamily HOWELLELLINAE Johnson & Hou (in Carter, Johnson, Gourvennee & Hou, 1994)

***Howellella* (*Howellella*) Kozłowski, 1946**

Type species. By original designation of Kozłowski (1946: 295); *Delthyris elegans* Muir-Wood, 1925; Middle Silurian of Angle.

***Howellella* (*Howellella*) *textilis* Talent, 1963**

Fig. 18E-M

Howellella textiles n. sp. Talent 1963: 81, pl. 50, figs 1-43.

Howellella cf. *textilis*-Johnson 1970a: 186, pl. 55, figs 1-19.-Chatterton 1973: 106, pl. 27, figs 1-19.-Lenz & Johnson 1985b: 89, pl. 12, figs 10-22.

Howellella (*Howellella*) *textilis*-Brock 2003b: 81, pl. 11, figs 11-16.

Material. Figured material: AM F117304 (Fig. 18E, F); ventral valve from MeL 420dh; AM F117305 (Fig. 18G, H); dorsal valve from MeL 420dh; AM F117306 (Fig. 18I-M); articulated specimen from MeL 420dh. Unfigured material: 62 ventral valves, 37 dorsal valves and 21 articulated specimens.

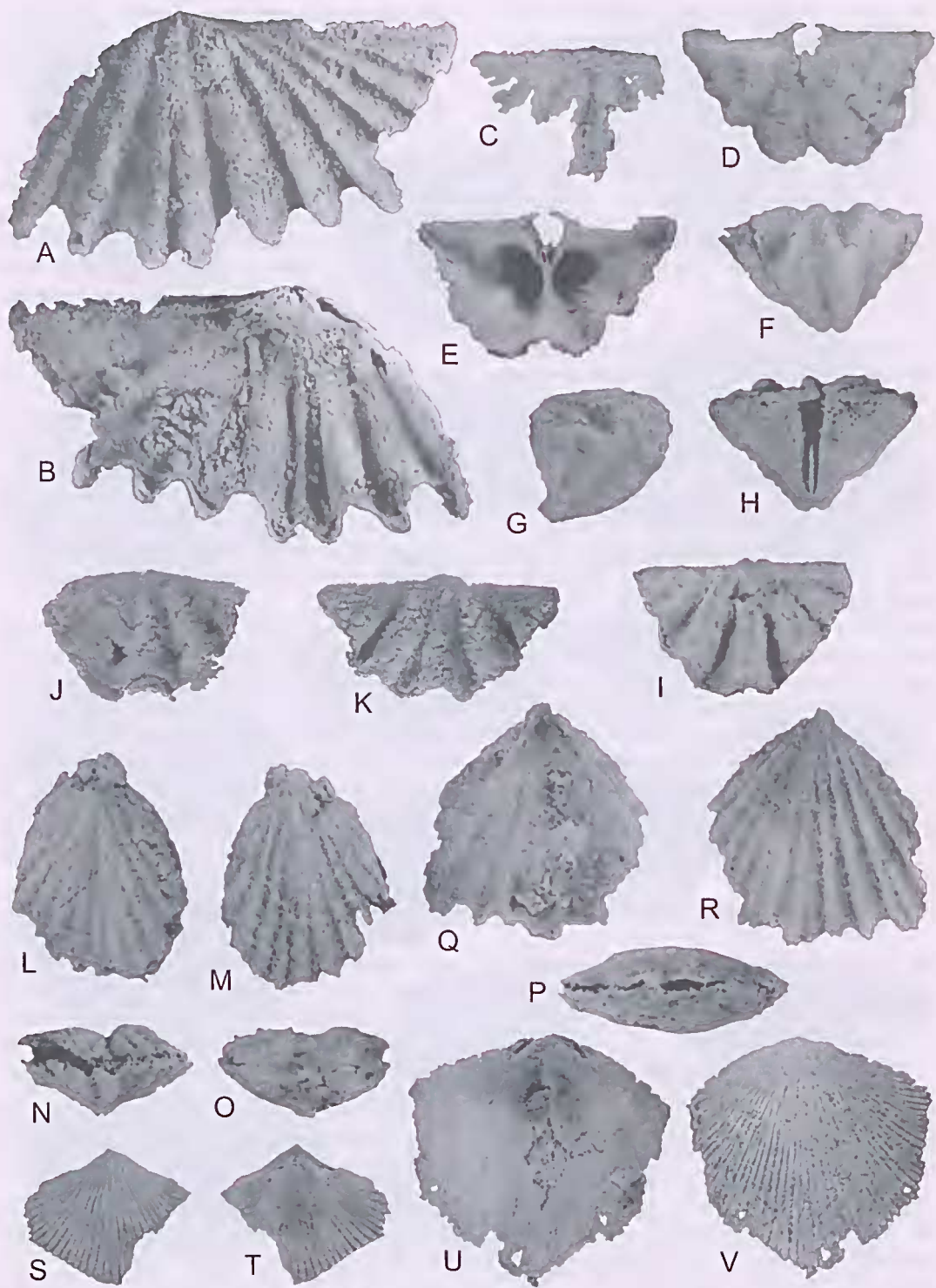
Description. See Talent (1963: 81).

Remarks. Most of the specimens recovered from the Murrindal Limestone closely resemble *H. (H.) textiles* from the late Pragian Lower Kilgower Member of the Tabberabbera Formation, differing only in some cases by possessing a greater number of plications and being slightly larger. However, these forms grade into forms identical to those described by Talent (1963).

Several species of *Howellella* have been reported from the Early Devonian Garra Limestone of New South Wales (Savage 1969; Lenz & Johnson 1985b; Farrell 1992; Brock 2003b). Of these, *H. (H.) textiles* appears most closely related to *H. nucula australis* Savage, 1969, but differs in possessing more plications, a stronger fold and sulcus and by being more transverse (Chatterton 1973). *Howellella talenti* Farrell, 1992 differs in possessing less prominent growth lamellae, lacking a myophragm in the ventral valve and crural plates that are convergent posteriorly and dorsally (Farrell 1992).

Mawson & Talent (1999) described four species of *Howellella*, *H. placoeotextilis*, *H. alatextilis*, *H. legirupa* and *H. sp.* from the Lochkovian Windellama Limestone of New South Wales. Both *H. placoeotextilis* and *H. alatextilis* appear to be closely related to *H. (H.) textiles*, but are distinguishable by differences in the ornament, with *H. (H.) textiles* having much narrower plications than the former and fewer plications than the latter. *Howellella alatextilis* also differs by being strongly alate (Mawson

Fig. 18. A-C, *Ambocoelia* sp. cf. *A. runnegari* (Chatterton, 1973). All specimens x 20. A, B, ventral valve interior and exterior, MeL 520, AM F117301. C, posterior view of articulated specimen, MeL 520, AM F117302. D, E, *Delthyris?* sp., ventral valve interior and exterior, MeL 520, AM F117303, x3. E-M, *Howellella* (*Howellella*) *textilis* Talent, 1963. All specimens x 7. F, G, dorsal valve interior and exterior, MeL 420dh, AM F117305. H, I, ventral valve interior and exterior, MeL 420dh, AM F117304. J-N, anterior, ventral, posterior, lateral and dorsal views of articulated specimen, MeL 420dh, AM F117306. O-S, *Howittia howitti* (Chapman, 1905), posterior, ventral, anterior and lateral views of articulated specimen, ROC 159, AM F117307, x7.



& Talent 1999). Whereas *H. legirupa* has a similar number and type of plications as *H. textilis*, it differs internally by possessing significantly larger dental plates as pointed out by Sherwin (1995).

Howittia Talent, 1956a

Type species. By original designation of Talent (1956a: 34); *Spirifer howitti* Chapman, 1905; latest Pragian to early Emsian of the Buchan Caves Limestone, Bindi, Victoria, Australia.

Howittia howitti (Chapman, 1905)

Figs 18N-R, 19A, B

Spirifer howitti sp. nov. Chapman 1905: 18, pl. 5, figs 4-6.

Howittia howitti-Talent 1956a: 34, pl. 2, figs 13-17.-Chatterton 1973: 112, pl. 24, figs 1-20.

Howittia cf. *H. howitti*-Lenz & Johnson 1985b: 90, pl. 14, figs 14-21.

Material. Figured material: AM F117307 (Fig. 18N-R); articulated specimen from ROC 159; AM F117308 (Fig. 19A, B); dorsal valve from ROC 159. Unfigured material: 10 ventral valves and three dorsal valves.

Description. See Chapman (1905: 18), Talent (1956a: 34) and Chatterton (1973: 112).

Remarks. These specimens can be readily assigned to *H. howitti* on the basis of the medial plication of the dorsal valve bearing a distinct groove, a feature Chapman (1905: 18) described as being one of the chief characteristics of *H. howitti*. *Howittia howitti* is very similar to *H. multiplicata* (de Koninek, 1876) from the Emsian limestones at Taemas (de Koninek 1876; Chatterton 1973) and the Lick Hole Formation at Ravine (Strusz et al. 1970), in terms of outline, microornament, delthyria, lateral plates and the subdivided fold and sulcus. However, they differ in that *H. multiplicata* has more plications, the fold of a mature dorsal valve is subdivided by at least five

furrows and that the plications next to the fold and sulcus of *H. multiplicata* are usually subdivided near the umbo. Internally, *H. multiplicata* has shorter crural plates (Chatterton 1973).

Howittia haideri Soja, 1988, from the Emsian of Kasaan Island, southeastern Alaska, differs from *H. howitti* in being smaller, having fewer plications and with three plications consistently on the fold and two in the sulcus. Internally, the two species are virtually identical, but *H. haideri* has much thicker dental plates. An unnamed species of *Howittia* described by Perry (1984), from Emsian strata of the Delorme Formation of Canada, differs in possessing less prominent ventral valve adminicula and fewer plications. A second unnamed species of *Howittia*, described by Johnson (1971) from the Emsian of the Sulphur Spring Range of central Nevada, possesses fewer and stronger plications. In addition, the plication on the sulcus is much larger than in *H. howitti* (Johnson 1971).

Numerous species of *Howittia* have also been described from China, many of which occur in the early Emsian Nanning-Liujing district of central Guangxi in southern China (Wang & Rong 1986). They consistently differ from *H. howitti* in possessing fewer plications, up to eight at most. In addition, most species also possess more plications in the fold and grooves in the sulcus than *H. howitti*, and lack growth lamellae developed over the entire shell.

Order SPIRIFERINIDA Ivanova, 1972

Remarks. The higher level classification used for the Spiriferinida herein follows that of Carter et al. (1994).

Suborder CYRTINIDINA Carter & Johnson (in Carter, Johnson, Gourvennee & Hou 1994)

Superfamily CYRTINOIDEA Frederiks, 1911

Family CYRTININAE Frederiks, 1911

Cyrtina Davidson, 1858a

Type species. By subsequent designation of Hall & Clarke (1894: 44); *Calceola heteroclita* DeFrance, 1824; Middle Devonian of western Europe.

Fig. 19. A, B, *Howittia howitti* (Chapman, 1905), dorsal valve exterior and interior, ROC 159, AM F117308, x 7. C-K, *Cyrtina wellingtonensis* Dun, 1904. All specimens x 5. C, dorsal valve interior, MeL 420dh, AM F117310. D, E, ventral valve exterior and interior, MeL 420dh, AM F117309. F-I, anterior, lateral, posterior and dorsal views of articulated specimen, ROC 162, AM F117311. J, dorsal valve exterior, MeL 420dh, AM F126356. K, dorsal view of articulated specimen, ROC 165, AM F126357. L-R, *Coelospira dayi* Chatterton, 1973. All specimens x 7. L-P, dorsal, ventral, anterior, posterior and lateral views of articulated specimen, MeL 497, AM F117312. Q, R, ventral valve interior and exterior, MeL 497, AM F117313. S-V, *Variatrypa (Variatrypa) erectirostris* (Mitchell & Dun, 1920). All specimens x 2. S, T, ventral valve exterior and interior, MeL 417, AM F117314. U, V, dorsal valve interior and exterior, ROC 162, AM F117315.

Cyrtina wellingtonensis Dun, 1904

Fig. 19C-K

Cyrtina wellingtonensis sp. nov. Dun 1904: 319, pl. 61, fig. 2-2e.-Broek 2003b: 85, pl. 9, figs 15-19; pl. 10, figs 1-4.

Cyrtina aff. *C. wellingtonensis*-Chatterton 1973: 101, pl. 23, figs 1-25.

?*Cyrtina* sp. 1 Lenz & Johnson 1985b: 87, pl. 11, figs 10-13.

Cyrtina sp. 2 Lenz & Johnson 1985b: 88, pl. 11, figs 14-17, 22.

?*Cyrtina* sp. 3 Lenz & Johnson 1985b: 88, pl. 11, figs 18-20, 22-25, 29.

Cyrtina sp. Broek & Talent 1993: 244, fig. 15A-E.

Material. Figured material: AM F117309 (Fig. 19D, E): ventral valve from MeL 420dh; AM F117310 (Fig. 19C): dorsal valve from MeL 420dh; AM F117311 (Fig. 19F-I): articulated specimen from ROC 162; AM F126356 (Fig. 19J): dorsal valve from MeL 420dh; AM F126357 (Fig. 19K): articulated specimen from ROC 165. Unfigured material: 98 ventral valves, 70 dorsal valves and 157 articulated specimens.

Description. See Dun (1904: 319) and Chatterton (1973: 101).

Remarks. *Cyrtina* is a cosmopolitan genus that exhibits a high degree of intraspecific variation, leading to great difficulties in distinguishing between species, not only within each collection, but also between collections. Kozłowski (1929), Chatterton (1973), Lenz (1977b), Perry (1984), Lenz & Johnson (1985b), Farrell (1992) and Broek (2003b) have all commented on these difficulties. This variation is so great that Lenz & Johnson (1985b) merely divided their specimens of *Cyrtina* from the Pragian Garra Limestone at Wellington into three unnamed species. Perry (1984) did not even attempt to identify individual species, claiming that only through the statistical analysis of large collections could individual species be accurately identified. Such a study has yet to be undertaken.

The specimens assigned to *Cyrtina* from the Murrindal Limestone have proved no exception to this rule. Like most *Cyrtina*, the interareas of the Murrindal specimens range from flat to strongly curved (Fig. 19D, E, G, H, I, K); the plications are weakly to strongly developed and rounded to angular (Fig. 19D, F, G, I, J, K); concentric growth lines

are faint and subdued to strongly developed (Fig. 19E, G, I, J, K); the cardinal extremities are rounded to angular (Fig. 19E, I, J, K); and some beaks are slightly twisted. As observed by Farrell (1992), these differences may be environmental in origin, a result of growth in a crowded environment, producing distorted shell growth.

Size has been frequently used to compare specimens of *Cyrtina* from different collections and to distinguish between different species (eg. Savage 1969; Farrell 1992). However, this appears to be an unreliable method of discriminating between individual species of *Cyrtina* as the size of many established species appears very similar. Broek (2003b: 86) has also shown that size can vary greatly intraspecifically.

A comparison of size versus the number of plications on the ventral and dorsal valves appears to separate eastern Australian specimens of *Cyrtina* into several distinct groups (Fig. 20). This analysis groups the Murrindal specimens with *C. wellingtonensis* from the Garra Limestone at Wellington (Dun 1904), *Cyrtina* sp. 2 from the Garra Limestone at Wellington (Lenz & Johnson 1985b), *C. wellingtonensis* from the Garra Limestone at Eurimbila (Broek 2003b), *Cyrtina* aff. *C. wellingtonensis* from the Emsian 'Receptaculites' and Warroo Limestone Members of the Taemas Limestone at Taemas (Chatterton 1973), and *Cyrtina* sp. from the Emsian Ukalunda Beds of Queensland (Broek & Talent 1993). The Murrindal specimens have therefore been assigned to *C. wellingtonensis*.

This analysis also allows the Murrindal specimens to be separated from *C. heteroclita*, *C. imbricata* Farrell, 1992 from the Garra Limestone of New South Wales (Savage 1969; Farrell 1992) and *C. praecedens* Kozłowski, 1929 from the Windellama Limestone in New South Wales (Mawson & Talent 1999) (Fig. 20).

Cyrtina sp. 2 and 3, described by Lenz & Johnson (1985b) from the Garra Limestone of New South Wales, plot slightly outside the range determined for *C. wellingtonensis* in this study (Fig. 20). Analysis of additional material is required to determine if these species also belong to *C. wellingtonensis*.

Order ATRYPIDA Rzhonsnitskaya, 1960

Suborder ATRYPIDINA Moore, 1952

Superfamily ATRYPOLIDEA Gill, 1871

Family ATRYPIDAE Gill, 1871

Subfamily ATRYPINAE Gill, 1871

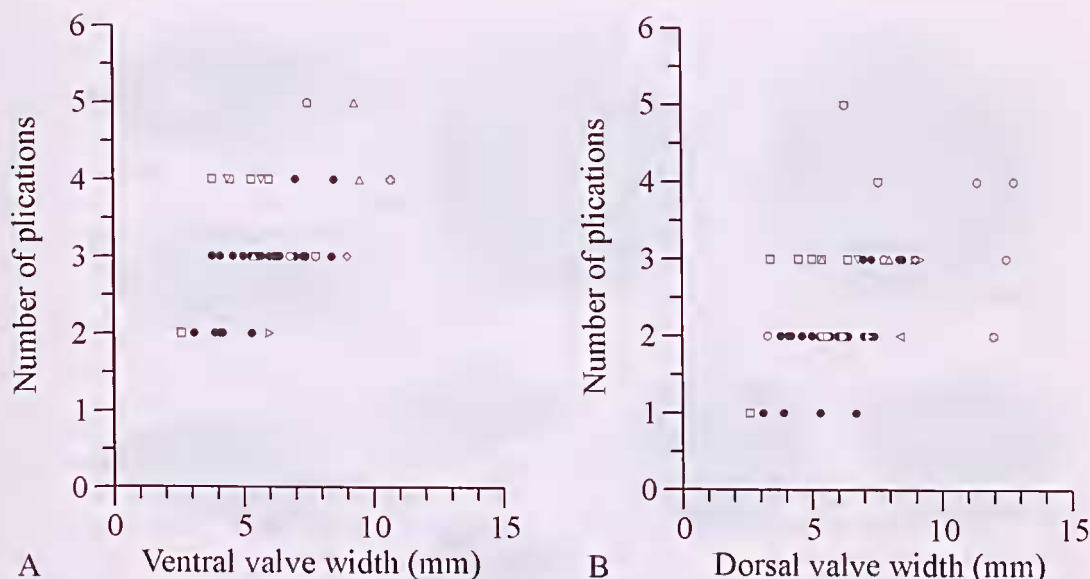


Fig. 20. Number of plications versus A, ventral valve width and B, dorsal valve width, for various Early Devonian species of *Cyrtina* from eastern Australia. ● *C. wellingtonensis* from the Murrindal Limestone, Buchan (A, $n = 29$; B, $n = 29$); ◇ *C. wellingtonensis* from the Garra Limestone, Wellington (A, $n = 1$; B, $n = 1$) (Dun 1904: pl. 61, fig. 2); ○ *C. aff. C. wellingtonensis* from the 'Receptaculites' and Warroo Limestone Members of the Taemas Limestone, Taemas (A, $n = 1$; B, $n = 5$) (Chatterton 1973: pl. 23, figs 1–25). ◁ *Cyrtina* sp. 1 from the Garra Limestone, Wellington (A, $n = 0$; B, $n = 1$) (Lenz & Johnson 1985b: pl. 11, figs 10–13); *Cyrtina* sp. 2 from the Garra Limestone, Wellington (A, $n = 0$; B, $n = 2$) (Lenz & Johnson 1985b: pl. 11, figs 14–17, 21); ▷ *Cyrtina* sp. 3 from the Garra Limestone, Wellington (A, $n = 1$; B, $n = 4$) (Lenz & Johnson 1985b: pl. 11, figs 18–20, 22–25, 29); *Cyrtina* sp. from the Ukalunda Beds, northeast Queensland (A, $n = 1$; B, $n = 1$) (Brock & Talent 1993: fig. 15A–E); △ *C. wellingtonensis* from the Garra Limestone, Eurimbla (A, $n = 3$; B, $n = 2$) (Brock 2003b); □ *C. praecedens* from the Mandagery Park Formation, Manildra (A, $n = 6$; B, $n = 6$) (Savage 1969: pl. 92, figs 1–44); *C. praecedens* from the Windellama Limestone, Windellama (A, $n = 2$; B, $n = 1$) (Mawson & Talent 1999: pl. 9, figs 15–19); *C. imbricata* from the Garra Limestone, The Gap (A, $n = 1$; B, $n = 3$) (Farrell 1992: pl. 5, figs 13–26); *Calceola heteroclita*, type species of *Cyrtina* (A, $n = 1$; B, $n = 1$) (Boucot et al. 1965: fig. 549, 10).

Atryparia Copper, 1966a

Type species. By original designation of Copper (1966a: 982); *Atryparia instita* Copper, 1966a; late Eifelian Müllert horizon, Ahbach beds, Germany.

Atryparia penelopeae (Chatterton, 1973)

Fig. 21F–V

Atrypa desquamata-Mitchell & Dun 1920: 271, pl. 15, figs 12, 13.

Desquamatia (*Synatrypa*) sp. nov. Hill, Playford & Woods 1967: pl. 20, figs 15, 16.

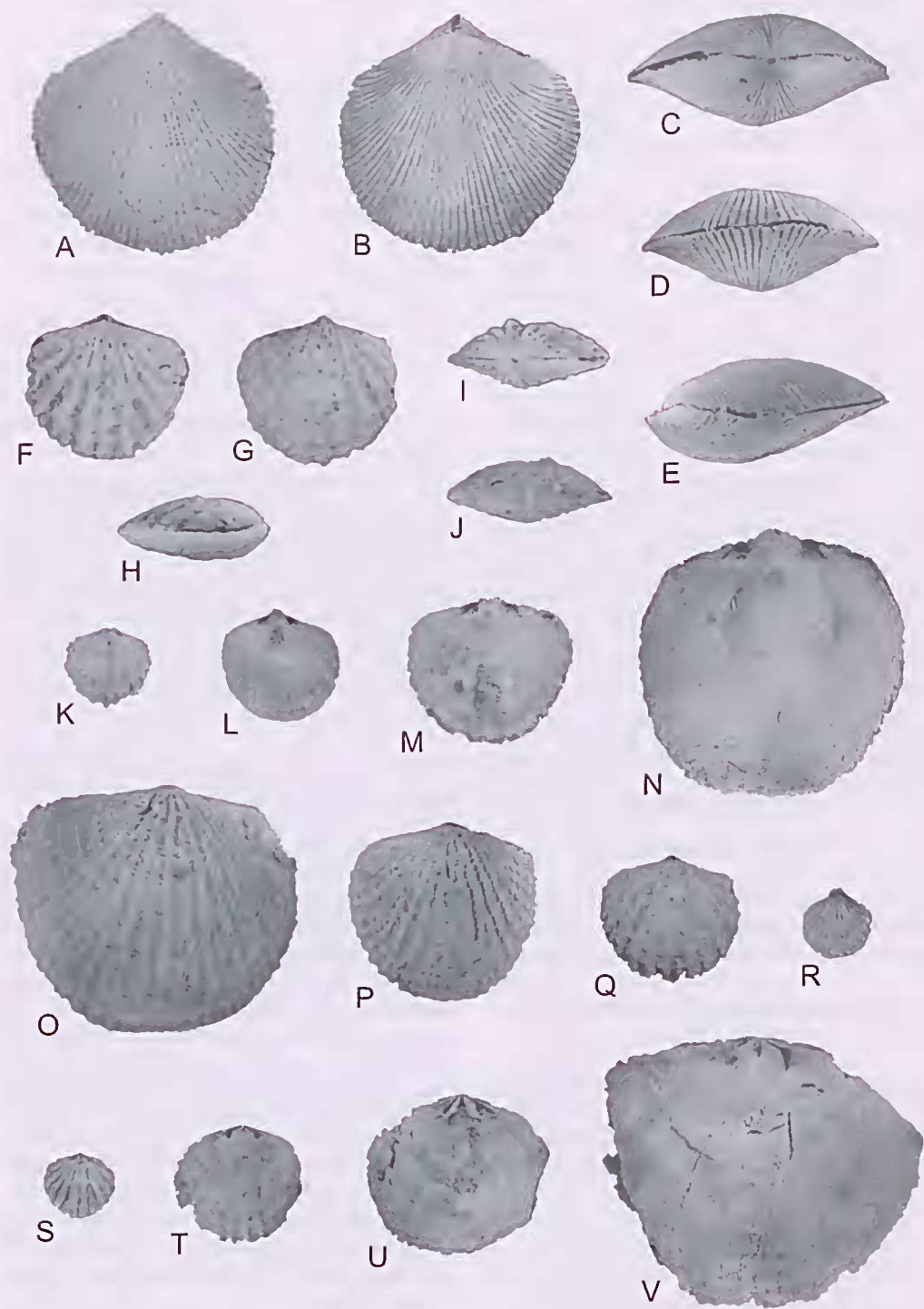
Atrypa penelopeae sp. nov. Chatterton 1973: 87, pl. 20, figs 15, 16; pl. 21, figs 12–23, 25–29; pl. 22, figs 1–10.

Desquamatia (*Variatrypa*) cf. *penelopeae*-Lenz & Johnson 1985b: 78, pl. 4, figs 4–14.

Atryparia penelopeae-Brock & Talent 1993: 239, fig. 11P–R; fig. 12A–J.

Material. Figured material: AM F117317 (Fig. 21F–J): articulated specimen from ROC 162; AM F117318 (Fig. 21K): ventral valve from ROC 162; AM F117319 (Fig. 21L): ventral valve from ROC 162; AM F117320 (Fig. 21M): ventral valve from ROC 162; AM F117321 (Fig. 21N): ventral valve from ROC 181; AM F117322 (Fig. 21O): articulated specimen from McL 417; AM F117323 (Fig. 21P): articulated specimen from McL 417; AM F117324 (Fig. 21Q): articulated specimen from ROC 162; AM F117325 (Fig. 21R): articulated specimen from ROC 162; AM F117326 (Fig. 21S): dorsal valve from ROC 162; AM F117327 (Fig. 21T): dorsal valve from ROC 162; AM F117328 (Fig. 21U): dorsal valve from ROC 162; AM F117329 (Fig. 21V): dorsal valve from ROC 162. Unfigured material: 779 ventral valves, 790 dorsal valves and 772 articulated specimens.

Description. See Chatterton (1973: 87).



Remarks. Brock & Talent (1993) believed the shape, growth lines, beak shape, lack of deltidial plates in mature specimens and the secondary thickening of shell material in the delthyrium of this species suggested its affinities lay with *Atryparia*, rather than *Atrypa* Dalman, 1828, where it was originally assigned by Chatterton (1973). Affinities with *Variatrypa* Copper, 1966b can be ruled out as the frill is not composed of a single piece. Unlike *Desquamatia* Aleksceva, 1960, adult specimens of *A. penelopeae* lack a well-developed interarea and possess coarse, rather than fine, costae.

Talent et al. (2001) questionably referred *A. penelopeae* to *Peetzatrypa* Rzhonsnitskaya, 1975, which occurs in the Eifelian Poluiakhtovsk Beds of the southwestern margin of the Kuzbass. *Peetzatrypa* possesses deltidial plates that are lacking in mature specimens of *A. penelopeae*, and weakly developed dental plates, that are thick and well developed in *A. penelopeae*. *Peetzatrypa* also possesses a high dorsal valve median ridge and spiralia with around ten whorls. *Atryparia penelopeae* has only a low dorsal valve median ridge, which is restricted to dividing the posterior half of the adductor scars and spiralia with as many as nineteen whorls (Chatterton 1973). Copper (2002) has recently synonymised *Peetzatrypa* with *Variatrypa*.

Ontogeny. Neanic specimens of *A. penelopeae* from the Murrindal Limestone are equibiconvex, or slightly ventribiconvex. A weakly developed fold in the ventral valve and sulcus in the dorsal valve may be present. A small pair of deltidial plates are observable in the delthyrium, defining a small, circular foramen (Fig. 21R). Several equally spaced growth lines are also observable with more added at regular intervals throughout growth (Fig. 21R). Muscle scars, if present, are only faintly impressed in each valve. The inner surface is strongly erenulate, a reflection of external ornament (Fig. 21K, S).

The dorsal valve of sub-adults has increased in convexity relative to the ventral valve, making them dorsibiconvex (Fig. 21H). The delthyrium, with its circular foramen and deltidial plates is still observable, but has begun to be reabsorbed (Fig. 21Q). Additional costae have arisen through intercalation and bifurcation (Fig. 21P, Q). Muscle scars are only

faintly impressed, with the ventral valve muscle scars being more firmly impressed than those of the dorsal valve (Fig. 21L, M, T, U). Slight pitting occurs in the ventral valve muscle field of some specimens, usually in those with the more firmly impressed muscle scars. The teeth have developed a faintly erenulate ridge running along their length and corresponding erenulated furrows are developed in the sockets of the dorsal valve (Fig. 21M, U). The internal surfaces have lost the strongly erenulated appearance, becoming smoother as the shells increase in size (Fig. 21L, M, T, U).

In adult and gerontic forms, the pedicle has been atrophied and the deltidial plates and foramen are absent, both having been resorbed (Fig. 21N, O). In association with this, secondary thickening of the shell around the delthyrium is prominent. The profile of adult *A. penelopeae* is strongly dorsibiconvex, the ventral valve being almost planar in some specimens. The muscle scars of both valves have become even more deeply impressed, but those of the dorsal valve are less firmly impressed than those of the ventral valve (Fig. 21N, V). A low ridge dividing the posterior portion of the dorsal valve muscle field has also been developed (Fig. 21V). The area around the muscle scars of both valves has become pitted, especially in the ventral valve (Fig. 21N). Stronger pitting is usually associated with more deeply impressed muscle scars. A frill is also developed in some adult and gerontic specimens of *A. penelopeae*.

Subfamily VARIATRYPINAE Copper, 1978

Variatrypa (*Variatrypa*) Copper, 1966b

Type species. By original designation of Copper (1966b: 12); *Desquamatia ajngata* Copper, 1965; lower Givetian Neuenbüsch horizon of the Blankenheim Syncline, northern Eifel, Germany.

Remarks. Copper (1966b) established *Variatrypa* as a subgenus of *Desquamatia*, but subsequently raised it to generic level (Copper 1978, 1991, 2002), diagnosing it as large, shield-shaped, dorsibiconvex with only one or two growth lines and a frill that is normally a single piece. According to Copper (1978: 294), *Anatrypa* may be distinguished from *Variatrypa* by its

Fig. 21. A-E, *Variatrypa* (*Variatrypa*) *erectirostris* (Mitchell & Dun, 1920), ventral, dorsal, posterior, anterior and lateral views of articulated specimen, McL 417, AM F117316, x 2. F-V, *Atryparia penelopeae* (Chatterton, 1973). All specimens x 2. F-J, dorsal, ventral, lateral, posterior and anterior views of articulated specimen, ROC 162, AM F117317. K-N, all ventral valve interiors. K-M, ROC 162, N, ROC 181, AM Fs117318-117321. O-R, all dorsal view of articulated specimens. O, P, McL 417, Q, R, ROC 162, AM Fs 117322-117325. S-V, all dorsal valve interiors, ROC 162, AM Fs 117326-117329.

biconvex profile, transversely subpentagonal outline, deltidial plates supported well into the interior of the pedicle cavity, medially directed teeth, thinner hinge plates, weakly developed cardinal process and thicker, ventrally directed erural bases. In contrast, Johnson & Boucot (1968) and Johnson (1970b, 1974a) argued that *Variatrypa* is best regarded as a subgenus of *Anatrypa*, due to similarities in ornament, the ventral valve interarea and delthyrium. The differences in shell shape between the type species of *Anatrypa* and *Variatrypa* were considered by Johnson & Boucot (1968) to be insignificant at the generic level. However, based on the differences discussed above, there seems sufficient differences between *Variatrypa* and *Anatrypa* to warrant a separate generic status for each.

Variatrypa (Variatrypa) erectirostris

(Mitchell & Dun, 1920)

Figs 19S-V, 21A-E

Atrypa erectirostris Mitchell & Dun 1920: 267, pl. 15, figs 10, 11; pl. 16, figs 17, 18.

Anatrypa erectirostris-Chatterton 1973: 92, pl. 20, figs 1-14, 17; pl. 21, figs 1-11, 24, 30-32; pl. 22, figs 11, 12.

Variatrypa (Variatrypa) erectirostris-Broek & Talent 1993: 243, fig. 12K-O; fig. 13 F-P.

Material. Figured material: AM F117314 (Fig. 19S, T): ventral valve from MeL 417; AM F117315 (Fig. 19U, V): dorsal valve from ROC 162; AM F117316 (Fig. 21A-E): articulated specimen from MeL 417. Unfigured material: 70 ventral valves, 30 dorsal valves and 106 articulated specimens.

Description. See Mitchell & Dun (1920: 267) and Chatterton (1973: 92).

Remarks. Chatterton (1973) declined to place this species from the Emsian 'Receptaculites' Limestone Member at Taemas, into either of the subgenera proposed by Copper (1966b) for *Anatrypa*. Chatterton (1973) believed this species to be larger than *A. (Synatrypa)* and possessing a ventral valve that is concave anterolaterally (Fig. 21C, D), and to be distinct from *A. (Variatrypa)* because it lacked a frill and possesses finer and more closely spaced costae (Figs 19S, V, 20A, B). However, Chatterton (1973) did note this species is probably closest to those forms assigned to *A. (Variatrypa)*. Broek & Talent (1993) provisionally reassigned this species to *Variatrypa (Variatrypa)*, following Copper (1978, 1991),

on the basis of the fine ribbing being interrupted by only a few growth lamellae. In addition, some specimens from the Murrindal Limestone, unlike those described by Chatterton (1973), possess growth lamellae developed into frills, further reinforcing this species affinities with *Variatrypa*.

Suborder DAYIINA Waagen, 1883

Superfamily ANOLOTHECOIDEA

Schuchert, 1894

Family ANOLOTHECIDAE Schuchert, 1894

Remarks. Following Johnson (1974b), Dagys (1996), Alvarez & Carlson (1998) and Alvarez et al. (1998), the Anoplotheidae (which includes *Coelospira* Hall, 1863, discussed below) are assigned to the superfamily Anoplotheoidea (following Alvarez et al. 1998) within the suborder Dayiina (following Johnson 1974b) in the order Atrypida. Although fundamental differences do exist between the Dayiina and the other atrypid suborders, and confusion surrounds their evolutionary relationships, there appears little justification at present to warrant their inclusion within the Athyrida as proposed by Copper (1973, 1986), Copper & Gourvennee (1996) and Alvarez & Copper (2002).

Subfamily COELOSPIRINAE Hall & Clark, 1895

***Coelospira* Hall, 1863**

Type species. By original designation of Hall (1863: 60); *Leptocoelia concava* Hall, 1857; Lochkovian of the lower Helderberg Group, Helderberg Mountain, New York, America.

***Coelospira dayi* Chatterton, 1973**

Fig. 19L-R

Coelospira dayi sp. nov. Chatterton 1973: 84, pl. 19, figs 15-36; pl. 35, figs 6-8.

Material. Figured material: AM F117312 (Fig. 19L-P): articulated specimen from MeL 497; AM F117313 (Fig. 19Q, R): ventral valve from MeL 497. Unfigured material: four ventral valves and 12 articulated specimens.

Description. See Chatterton (1973: 84).

Remarks. *Coelospira concava* (see Boucot & Johnson 1967: 1235-1236 for locality information) shows considerable morphological variation, espe-

cially in the length to width ratio and in the character of the median rib of the ventral valve. *Coelospira dayi* differs most consistently from *C. concava* in having a ventral valve muscle field that is not anteriorly elevated on a platform.

Coelospira dayi was the first species of *Coelospira* to be documented in Australia. Previously, Devonian *Coelospira* were believed to have been restricted to Laurentia, apart from a single specimen recovered from Turkey (Boucot & Johnson 1967). However, since then *Coelospira* has also been recovered from northern Mexico, South America and Asia, ranging from Lochkovian to Eifelian in age (Alvarez & Copper 2002). Several additional species of *Coelospira* have also been described from Australia.

Coelospira praedayi Lenz & Johnson, 1985b, from the Pragian Garra Limestone at Wellington is closely related to *C. dayi*. Both species have a similar shape and ornament, but *C. dayi* is more elongate, possesses a shorter median costa on the ventral valve and shorter, weaker secondary costae. *Coelospira septata* Lenz & Johnson, 1985b, also from the Pragian Garra Limestone at Wellington (Lenz & Johnson 1985b) and the Pragian Garra Limestone at Eurimbla (Broek 2003b), is more rounded, possesses more costae in the dorsal valve sulcus compared to *C. dayi* and has a thread-like median ridge in the ventral valve and a prominent median septum in the dorsal valve (Lenz & Johnson 1985b). An indeterminate specimen referred to as *Coelospirinae* gen. indet. by Savage (1974) from the ?early Lochkovian Maradana Shale has been referred to *Coelospira* by Talent et al. (2001). This species differs primarily from *C. dayi* in bearing more costae.

Coelospira sp., documented by Broek & Talent (1993) from the Emsian Ukalunda Beds and Douglas Creek of Queensland, possesses a similar outline, incurvature of the beak and growth lines to *C. dayi*. However, *C. dayi* is distinguishable by its well-developed dorsal valve sulcus (Fig. 19L, N) and ventral valve with a fine medial plication flanked by a pair of large costae (Fig. 19M, R). The Ukalunda and Douglas Creek specimens also possess a number of features unique to *Coelospira*, such as the presence of up to three well-developed ventral medial costae and costae which increase by bifurcation on the ventral valve and usually by implantation on the dorsal valve. Broek & Talent (1993: 239) speculated that this unusual combination of features may indicate these specimens represent a new species of *Coelospira*, but additional material is required to confirm this. Hill et al. (1967: pl. D12, fig. 6) figured a single specimen of *Coelospira* from the

Ukalunda Beds that appears externally similar to those specimens described by Broek & Talent (1993), although it has a somewhat narrower outline.

Order ATHYRIDIDA Boucot, Johnson & Stanton, 1964

Suborder ATHYRIDINA Boucot, Johnson & Stanton, 1964

Superfamily ATHYRIDOIDEA Davidson, 1881

Family ATHYRIDIDAE Davidson, 1881

Subfamily DIDYMOTHYRIDINAE
Modzalevskaia, 1979

Buchanathyris Talent, 1956a

Type species. By original designation of Talent (1956a: 36); *Buchanathyris westoni* Talent, 1956a; Early Emsian Buchan Caves Limestone, Buchan, Victoria, Australia.

Buchanathyris westoni Talent, 1956a
Fig. 22A-J

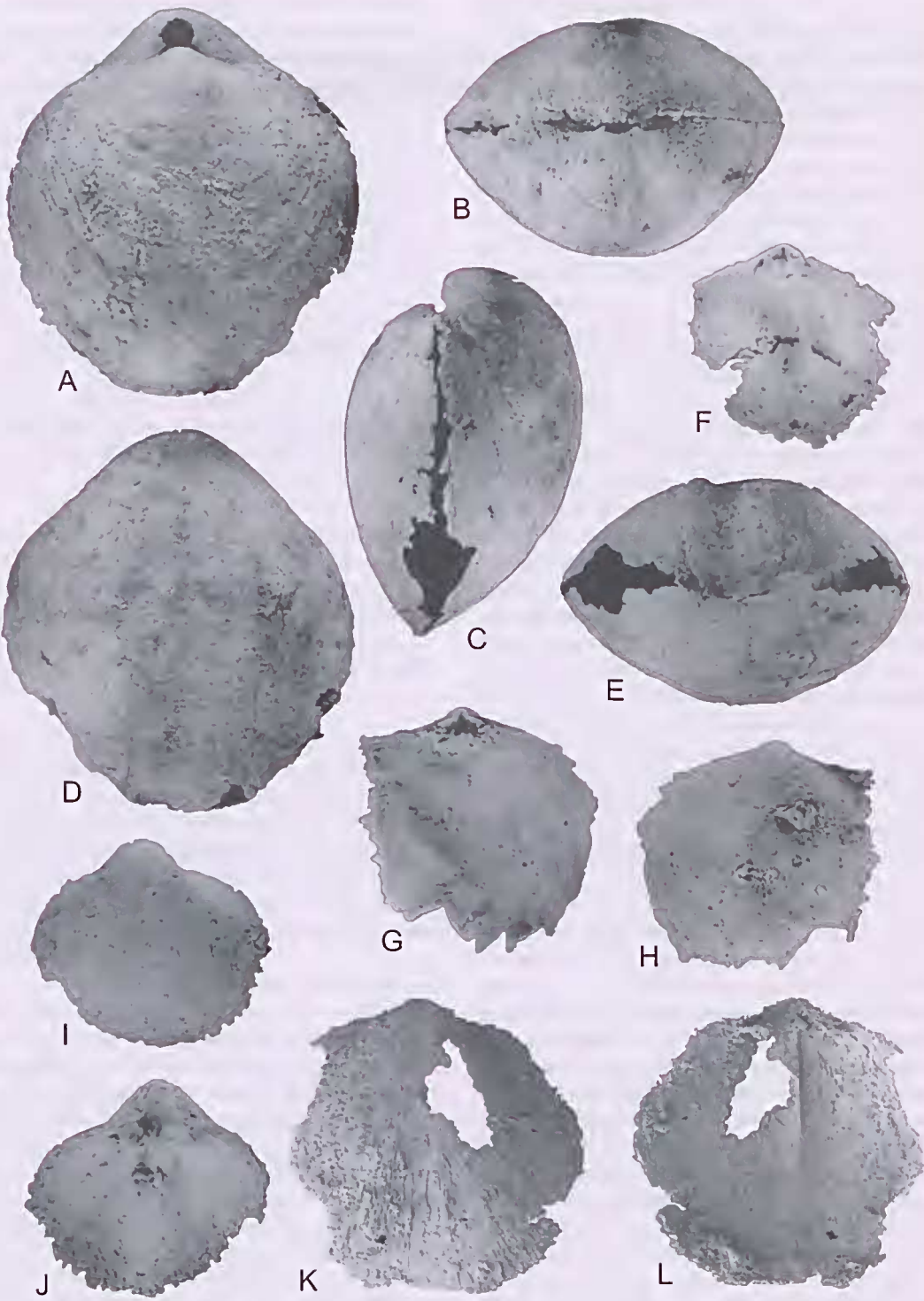
Buchanathyris westoni sp. nov. Talent 1956a: 36, pl. 3, figs 1–4.

Buchanathyris westoni?-Talent 1963: 87, pl. 59, figs 5–11.

Material. Figured material: AM F117330 (Fig. 22A–E): articulated specimen from ROC 162; AM F117331 (Fig. 22F): dorsal valve from ROC 162; AM F117332 (Fig. 22G, H): dorsal valve from ROC 165; AM F117333 (Fig. 22I, J): ventral valve ROC 162. Unfigured material: 210 ventral valves, 229 dorsal valves and 32 articulated specimens.

Description. See Talent (1956a: 36).

Remarks. Although no features of the lophophore support or jugum have been preserved, the presence of a short and apically perforated hinge plate, fairly well developed concave dental plates and lack of a median septum (Fig. 22F, G, J), indicates the affinities of this taxon lie with *Buchanathyris*. The ornament, consisting of fine concentric growth lines at best (Fig. 22A, D), associates these specimens with *B. westoni*, which also occurs in the early Emsian Buchan Caves Limestone and Pragian Dead Bull Member of the Tabberabbera Formation of Victoria (Talent 1956a). The ornament also separates this species from *B. waratahensis* Talent, 1956a, from the latest Pragian Bell Point



Limestone in Victoria, which possesses projecting growth lines. *Buchanathyris? pulchra* Talent, 1963 (questionably referred to *Athyris?* by Talent et al. 2001) from the ?early Emsian Roaring Mag Member of the Tabberabbera Formation of Victoria, differs from *B. westoni* in possessing a well defined sulcus in the ventral valves, a poorly developed fold in the dorsal valve and well developed growth lamellae.

The majority of the specimens recovered from the Murrindal Limestone differ from Talent's (1956a) original description of *B. westoni* in possessing a thread-like median ridge in the dorsal valve that extends anteriorly to approximately valve midlength. Associated with this ridge are long, thin impressions of muscle scars which extend forward no further than the median ridge (Fig. 22F, G). These two features are highly variable and at any given stratigraphic horizon they range from indistinct to strongly developed. Talent (1963) did not mention the presence or absence of dorsal muscle scars in *B. westoni* from the Buchan Caves Limestone, but he stated that the dorsal valve lacked a median septum. Talent (1963) described *B. westoni?* from the Tabberabbera Formation as possessing elongate muscle scars in the dorsal valve and a variably developed, often faint, median septum.

Buchanathyris has also been recovered from China. *Buchanathyris subplana* (Tien, 1938), from the Devonian of Sichuan Province (Wang et al. 1974) is slightly more elongate, but is not as thick and has a weaker beak and smaller foramen compared to *B. westoni*.

Superfamily NUCLEOSPIROIDEA Davidson, 1881
Family NUCLEOSPIRIDAE Davidson, 1881

Nucleospira Hall in Davidson, 1858b

Type species. By monotypy, Hall in Davidson (1858b: 412); *Spirifer ventricosus* Hall, 1857; Lochkovian of the lower Helderberg Group, Helderberg Mountain, New York, America.

Nucleospira sp.
Fig. 22K, L,

Material. Figured material: AM F117334 (Fig. 22K, L): ventral valve from McL 495. Unfigured material: one ventral valve.

Fig. 22. A-J, *Buchanathyris westoni* Talent, 1956a. All specimens x 3. A-E, dorsal, posterior, lateral, ventral and anterior views of articulated specimen, ROC 162, AM F117330. F, dorsal valve interior, ROC 162, AM F117331. G, H, dorsal valve interior and exterior, ROC 165, AM F117332. I, J, ventral valve exterior and interior, ROC 162, AM F117333. K, L, *Nucleospira* sp., ventral valve exterior and interior, McL 495, AM F117334, x 18.

Remarks. It is not possible to assign the Murrindal specimens to a described species of *Nucleospira* due to the limited and inadequately preserved material. However, the shells appear to differ from most other described species of *Nucleospira* in that the median septum of the ventral valve does not extend beyond valve midlength. The Murrindal specimens appear most similar to those described by Philip (1962) from the late Lochkovian Boola Siltstone of the Tyers-Boola area of central Victoria and Talent (1963) from the Pragian Lower Kilgower Member of the Tabberabbera Formation. The Tyers Boola specimens possess a median septum with an ill-defined anterior portion (Philip 1962), whereas the length of the median septum is variable in the Tabberabbera specimens (Talent 1963).

Based on this difference in the length of the median septum alone, the Murrindal specimens may represent a new species of *Nucleospira*. However, most species of *Nucleospira* are very similar externally and internally (Savage 1981). Bowen (1967: 38) and Savage (1981: 366) both stated that new species of *Nucleospira* are assigned primarily on differences in the distinctiveness of the sulcus, valve convexity, the length to width ratio, growth lines and size. It is difficult to determine these characteristics for the Murrindal specimens. In addition, these characteristics appear highly variable both between and within species and the range of variation between species remains unknown (Bowen 1967; Savage 1981). As a result, many workers, such as Johnson (1970a), Harper (1973), Boucot (1973) and Smith (1980), have declined to name individual species.

Order TEREBRATULIDA Waagen, 1883

Remarks. The higher level classification used for the Terebratulida herein follows that of Boucot & Wilson (1994).

Suborder CENTRONELLIDINA Stehli, 1965
Superfamily STRINGOCEPHALOIDEA
King, 1850

Family MEGANTERIDAE Schuchert & Levene, 1929

Subfamily ADRENINAE Boucot in Boucot & Wilson, 1994

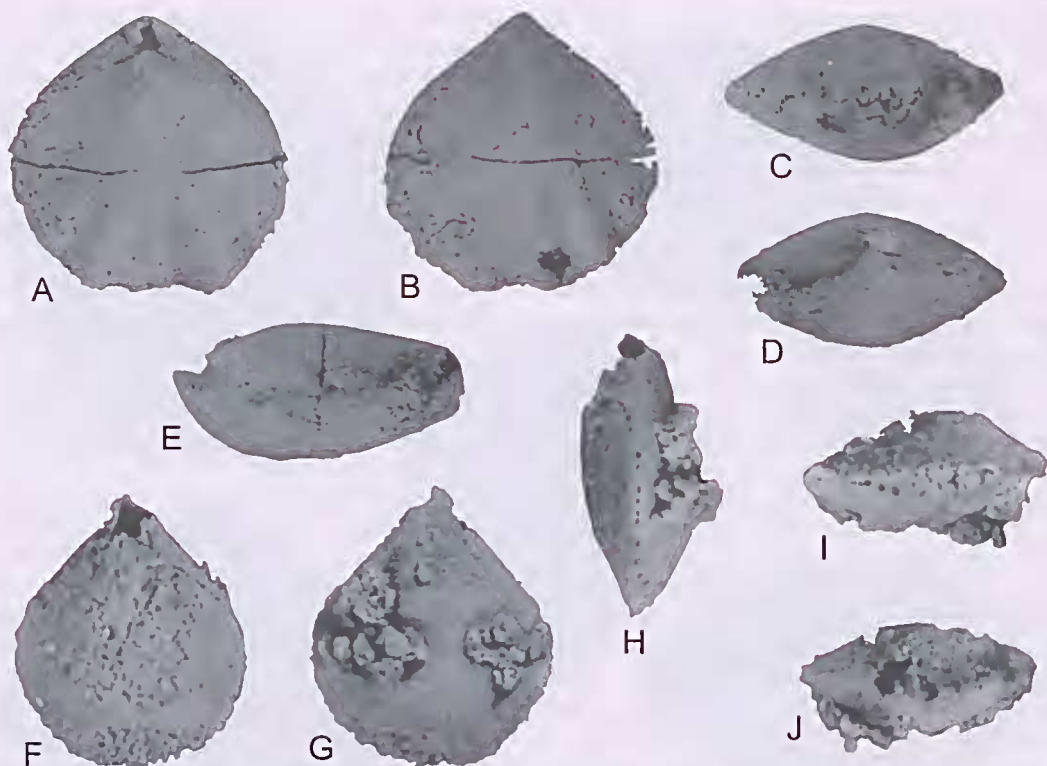


Fig. 23. A-E, *Micidus shandkyddi* Chatterton, 1973, dorsal, ventral, anterior, posterior and lateral views of articulated specimen, ROC 162, AM F117335, x 5. F-J, *Micidus? glaber* Chatterton, 1973, dorsal, ventral, lateral, anterior and posterior views of articulated specimen, McL 497, AM F117336, x 12.

Micidus Chatterton, 1973

Type species. By original designation of Chatterton (1973: 137); *Micidus shandkyddi* Chatterton, 1973; early Emsian 'Receptaculites' Limestone Member, Taemas Limestone, Taemas, New South Wales, Australia.

Micidus shandkyddi Chatterton, 1973

Fig. 23A-E

Micidus shandkyddi gen. et sp. nov. Chatterton 1973: 137, pl. 34, figs 1-12.

?*Micidus?* spp. A. Lenz & Johnson, 1985b: 93, pl. 16, figs 7-24.

?*Micidus?* spp. B Lenz & Johnson 1985b: 93, pl. 16, figs 20, 25-35.

Material. Figured material: AM F117335 (Fig. 23A-E); articulated specimen from ROC 162. Unfigured material: two dorsal valves and 22 articulated specimens.

Description. See Chatterton (1973: 137).

Remarks. Chatterton (1973) separated *M. shandkyddi* from *M? glaber* Chatterton, 1973, primarily on differences in external features. These include the presence of anterolateral plications, a weakly developed fold and sulcus, a weakly sulcate anterior commissure and a submesothyridid (to hypothyridid?) foramen in *M. shandkyddi*. The external features and dimensions of the Murrindal specimens compare well with *M. shandkyddi* from the Emsian 'Receptaculites' Limestone Member, although the Murrindal specimens are slightly larger (Fig. 24). It is not possible to compare internal features though as none of the specimens recovered from the Murrindal Limestone shows any trace of internal preservation.

Lenz & Johnson (1985b) tentatively referred two species from the Pragian Garra Limestone at Wellington to *Micidus* as they possessed simple deltidial plates. *Micidus?* spp. A closely resembles *M. shandkyddi*, both possessing a similar number of

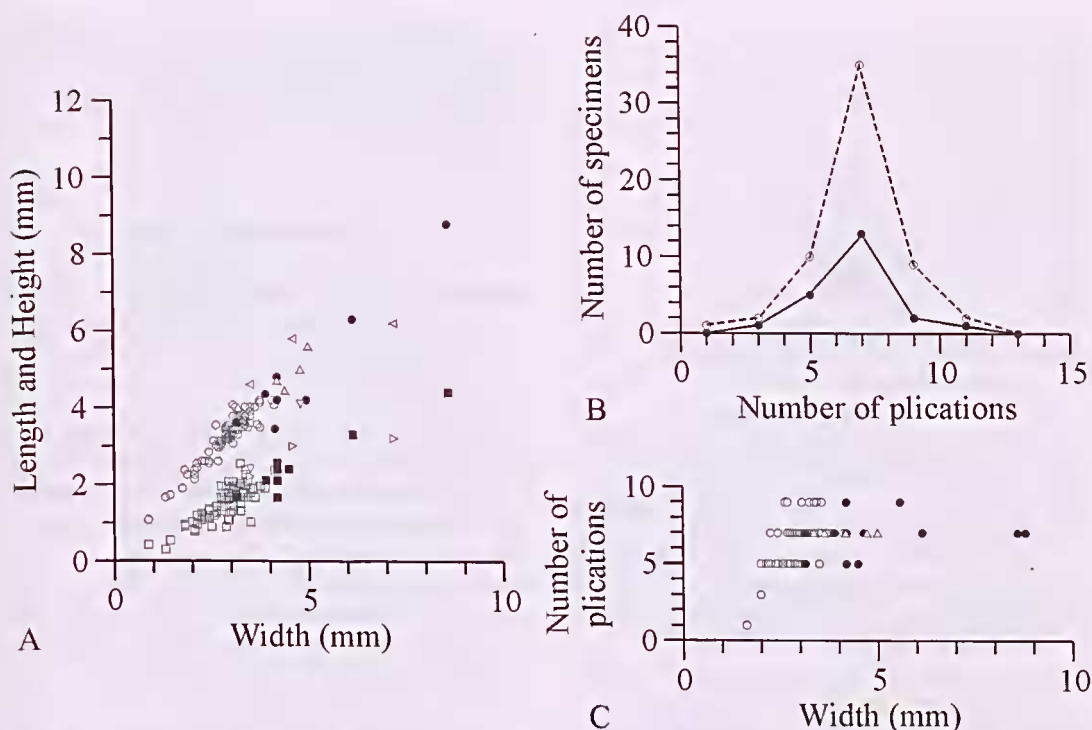


Fig. 24. Comparison of *M. shandkyddi* from the 'Receptaculites' Limestone Member at Taemas (average width 2.87 mm; length 3.22 mm; height 1.5 mm; number of plications 6.9) (Chatterton 1973: fig. 49), with *M. shandkyddi* from the Murrindal Limestone (average width 4.71 mm; length 4.96 mm; height 2.42 mm; number of plications 6.73) and *M. spp. A* from the Garra Formation (average width 4.15 mm; length 4.75 mm; height 3.25 mm; number of plications 7) (Lenz & Johnson 1985b: pl. 16, figs 7–24) and *M?* spp. B from the Garra Formation (average width 5.1 mm; length 5.53 mm; height 2.8 mm) (Lenz & Johnson 1985b: pl. 16, figs 20, 25–35). A, Length versus width of ● Murrindal specimens ($n = 8$), ○ Taemas specimens ($n = 72$), △ *M. spp. A* ($n = 4$) and ◁ *M?* spp. B ($n = 3$); height versus width of ■ Murrindal specimens ($n = 10$), □ Taemas specimens ($n = 75$), ▽ *M. spp. A* ($n = 2$) and ▷ *M?* spp. B ($n = 3$). B, Number of specimens versus number of plications of ● Murrindal ($n = 22$) and ○ Taemas specimens ($n = 60$). C, Number of plications versus width of ● Murrindal specimens ($n = 13$), ○ Taemas specimens ($n = 45$) and △ *M. spp. A* ($n = 5$).

plications and dimensions, although they too are somewhat larger than *M. shandkyddi* (Fig. 17). The Garra specimens differ, however, in possessing sharply rounded to angular plications. *Micidus?* spp. B possesses 2–3 pairs of rounded to angular eostae that are at best weakly developed on the anterior half to third of the valve, compared to 5–11 plications on the dorsal valve of *M. shandkyddi*. Despite this external difference from *M. shandkyddi*, Lenz & Johnson (1985b) note that the crural plates and loops of *M?* spp. B are the same as those in *M?* spp. A.

Micidus stellae Soja, 1988, from the Emsian of Kasaan Island, southeastern Alaska, differs in having fewer plications along the anterior margins (three on the dorsal valve and two on the ventral valve) and inner hinge plates that are united anteriomedially.

Micidus? glaber Chatterton, 1973

Fig. 23F–J

Micidus? glaber sp. nov. Chatterton 1973: 138, pl. 30, figs 1–15.

Material. Figured material: AM F117336 (Fig. 23F–J): articulated specimen from MeL 497. Unfigured material: 31 articulated specimens.

Description. See Chatterton (1973: 138).

Remarks. Chatterton (1973) tentatively referred this species from the top of the Emsian 'Receptaculites' Limestone Member to *Micidus* due to internal similarities with *M. shandkyddi*, despite the fact it dif-

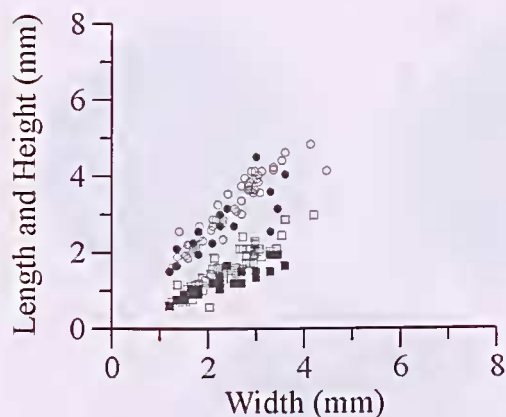


Fig. 25. Comparison of *M? glaber* from the 'Receptaculites' Limestone Member at Taemas (average width 2.51 mm; length 3.19 mm; height 1.65 mm) (Chatterton 1973: fig. 50), with *M? glaber* from the Murrindal Limestone (average width 2.33 mm; length 2.73 mm; height 1.23 mm). Length versus width of ● Murrindal ($n=16$) and ○ Taemas specimens ($n=53$). Height versus width of ■ Murrindal ($n=23$) and □ Taemas specimens ($n=53$).

ferred in lacking plications. The Murrindal specimens closely resemble *M? glaber* externally (Fig. 25). No specimens with internal structures preserved have been recovered from the Murrindal Limestone and the exact taxonomic status of this species must therefore remain doubtful.

Micidus stellae Soja, 1988, from the Emsian of Kasaan Island, southeastern Alaska, is easily distinguished by the presence of three plications developed along the anterior margin of the dorsal valve and two on the ventral valve.

ACKNOWLEDGEMENTS

I am much indebted to Prof. John Talent, Assoc. Prof. Ruth Mawson and Dr. Glenn Broek for making this project available to me and providing support and advice on everything from taxonomy to comments on the final draft. Brett Pyemont and the GEOS 425 Palaeobiology class of 2000 provided support with fieldwork. Michael Engelbrechtsen assisted with acid leaching and Belinda Kyle helped pick numerous samples. David Matheison and Margaret Anderson provided invaluable assistance with photography and plate making. Dean Oliver skillfully drafted the maps and stratigraphic columns. This manuscript greatly benefited from comments provided by Art Boucot and Tony Wright.

This report is a contribution towards documentation of the brachiopod faunas of the Murrindal Limestone, and to IGCP Project 421: *North Gondwana mid-Palaeozoic bioevent/biogeography patterns in relation to crustal dynamics*.

REFERENCES

- AMSDEN, T. W., 1968. Articulate brachiopods of the St. Clair Limestone (Silurian), Arkansas, and the Clarita Formation (Silurian), Oklahoma. *Paleontological Society Memoir* 1: 1–117.
- AMSDEN, T. W., 1974. Late Ordovician and Early Silurian articulate brachiopods from Oklahoma, southwestern Illinois and eastern Missouri. *Oklahoma Geological Survey Bulletin* 119: 1–154.
- ALBERTI, G. K. B., 1993. Dacryoconaride und homoetenide Tentaculiten des Unter- und Mittel-Devons I. *Courier Forschungsinstitut Senckenberg* 158: 1–229.
- ALBERTI, G. K. B., 1995. Planktonic tentaculitid correlation with conodont zonation in the south-east Australian Lower Devonian. *Courier Forschungsinstitut Senckenberg* 182: 557–558.
- ALEKSEEVA, R. E., 1960. O novom podrode *Atrypa* (*Desquamatia*) subgen. semestva Atrypidae Gill (Brachiopody). *Doklady Akademii Nauk SSSR* 131: 421–424.
- ALVAREZ, F. & CARLSON, S. J., 1998. Evolución y relaciones filogenéticas entre los grupos de mayor rango taxonómico de atrídeos y otros "braquiópodos articulados". *Revista Española de Paleontología* 13: 209–234.
- ALVAREZ, F. & COPPER, P. 2002. Uncertain. In *Treatise on Invertebrate Paleontology, part H, Brachiopoda, revised, volume 4: Rhynchonelliformea (part)*, R. L. Kaesler, ed. Geological Society of America and University of Kansas Press, Boulder and Lawrence, 1604–1614.
- ALVAREZ, F., RONG JIA-YU & BOUCOT, A. J., 1998. The classification of athyrid brachiopods. *Journal of Paleontology* 72: 827–855.
- ANDERSON, M. M., BOUCOT, A. J. & JOHNSON, J. G., 1969. Eifelian brachiopods from Padaupkin, northern Shan States, Burma. *Bulletin of the British Museum of Natural History (Geology)* 18: 105–163.

- BANCROFT, B. B., 1928. On the notational representation of the rib system in Orthacea. *Memoir and Proceedings of the Manchester Literary and Philosophical Society* 72: 52–90.
- BANCROFT, B. B., 1945. The brachiopod zonal indices of the stages Costonian-Onnian in Britain. *Journal of Paleontology* 19: 181–252.
- BARRANDE, J., 1847. Über die Brachiopoden der silurischen Schichten von Böhmen. *Naturwissenschaftliche Abhandlungen* 1: 357–475.
- BARRANDE, J., 1848. Über die Brachiopoden der silurischen Schichten von Böhmen. *Naturwissenschaftliche Abhandlungen* 2: 155–256.
- BARRANDE, J., 1879. *Système Silurien du centre de la Bohême. Recherches paléontologiques, vol. 5. Classe des Mollusques. Ordre des Brachiopodes*. Published by the author, Prague and Paris, xiv+226 pp.
- BASDEN, A., 1999. Emsian (Early Devonian) microvertebrates from the Buchan and Taemas areas of southeastern Australia. *Records of the Western Australian Museum, Supplement* 57: 15–22.
- BELL, K. N., 1996. Early Devonian (Emsian) agglutinated foraminiferans from Buchan and Bindi, Victoria, Australia. *Proceedings of the Royal Society of Victoria* 108: 73–106.
- BELL, K. N. & WINCHESTER-SEETO, T. M., 1999. Linings of agglutinated foraminifera from the Devonian: taxonomic and biostratigraphic implications. *Journal of Micropalaeontology* 18: 27–43.
- BIERNAT, G., 1959. Middle Devonian Orthoidea of the Holy Cross Mountains and their ontogeny. *Palaeontologica Polonica* 10: 1–78.
- BIERNAT, G. & BEDNARCZYK, W., 1990. Evolutionary crisis within the Ordovician acrotretid inarticulate brachiopods of Poland. In *Extinction Events in Earth History*, E. G. Kaufman & O. H. Walliser, eds. *Lecture Notes in Earth History* 30: 105–114.
- BIERNAT, G. & HARPER, D. A. T., 1999. A lingulate brachiopod *Aeroretella*: new data from Ordovician of Poland. *Acta Palaeontologica Polonica* 44: 83–92.
- BOUCOT, A. J., 1973. Early Paleozoic brachiopods of the Moose River Synclinorium, Maine. *United States Geological Survey Professional Paper* 784: 1–81.
- BOUCOT, A. J. & JOHNSON, J. G., 1967. Species and distribution of *Coelospira* (Brachiopoda). *Journal of Paleontology* 41: 1226–1241.
- BOUCOT, A. J., JOHNSON, J. G., PITRAT, C. W. & STATON, R. D., 1965. Spiriferida. In *Treatise on Invertebrate Paleontology, part H, Brachiopoda, volume 2*, R. C. Moore, ed. Geological Society of America and University of Kansas Press, Lawrence, H632–H728.
- BOUCOT, A. J. & WILSON, R. A., 1994. Origin and early radiation of terebratuloid brachiopods: thoughts provoked by *Proreus-selaeria* and *Nautothyris*. *Journal of Paleontology* 68: 1002–1025.
- BOWEN, Z. P., 1967. Brachiopoda of the Kayser Limestone (Silurian-Devonian) of Maryland and adjacent areas. *Geological Society of America Memoir* 102: 1–103.
- BROCK, G. A., 1989. *Middle Devonian (Givetian) atrypids from the Papilio Formation, north Queensland, Australia*. MSc thesis, Macquarie University, Sydney (unpubl.).
- BROCK, G. A., 2003a. Lochkovian (Early Devonian) brachiopods from the Garra Limestone at Eurimbla, New South Wales, Australia. Part 1: Acrotretida, Strophomenida, Productida, Orthotetida, Orthida and Pentamerida. *Palaeontographica Abt. A* 269: 93–136.
- BROCK, G. A., 2003b. Lochkovian (Early Devonian) brachiopods from the Garra Limestone at Eurimbla, New South Wales, Australia. Part 2: Rhynchonellida, Atrypida, Athyridida and Spiriferida. *Palaeontographica Abt. A* 270: 49–94.
- BROCK, G. A., ENGELBRETSSEN, M. J. & DEAN-JONES, G., 1995. Acrotretoid brachiopods from the Devonian of Victoria and New South Wales. *Memoirs of the Association of Australasian Palaeontologists* 18: 105–120.
- BROCK, G. A. & TALENT, J. A., 1993. Emsian (Early Devonian) brachiopods from the Ukalunda Beds and Douglas Creek, north Queensland. *Memoirs of the Association of Australasian Palaeontologists* 15: 225–248.
- BRUNTON, C. H. C. & COCKS, L. R. M., 1996. The classification of the brachiopod order Strophomenida. In *Brachiopods*, P. Copper & J. Jin, eds. A.A. Balkema, Rotterdam, 47–51.
- BURROW, C. J. & TURNER, S., 1998. Devonian placoderm scales from Australia. *Journal of Vertebrate Paleontology* 18: 677–695.

- CAMPBELL, K. S. W. & TALENT, J. A., 1967. *Malurostrophlia*, a new genus of stropheodontid brachiopod from the Devonian of Australia. *Proceedings of the Royal Society of Victoria* 80: 309–330.
- CARTER, J. L., JOHNSON, J. G., GOURVENNEC, R. & HOU HONG-FEI, 1994. A revised classification of the spiriferid brachiopods. *Annals of the Carnegie Museum* 63: 327–374.
- CASTER, K. E., 1939. A Devonian fauna from Colombia. *Bulletin of American Paleontology* 24: 1–218.
- CHAPMAN, F., 1905. New or little-known Victorian fossils in the National Museum, Melbourne: part VI.—Notes on Devonian spirifers. *Proceedings of the Royal Society of Victoria* 18: 16–19.
- CHAPMAN, F., 1913. New or little-known Victorian fossils in the National Museum, part 16, some Silurian Brachiopoda. *Proceedings of the Royal Society of Victoria* 26: 99–113.
- CHAPMAN, F., 1914. *Australasian fossils*. G. Robertson & Co., Melbourne, 341 pp.
- CHATTERTON, B. D. E., 1973. Brachiopods of the Murrumbidgee Group, Tacmas, New South Wales. *Bureau of Mineral Resources, Geology and Geophysics Bulletin* 137: 1–146.
- CHATTERTON, B. D. E. & PERRY, D. G., 1978. An early Eifelian invertebrate faunule, Whittaker Anticline, northwestern Canada. *Journal of Paleontology* 52: 28–39.
- CHEN XIU-QIN, KUANG GUO-DUN & RONG JIA-YU, 1989. Brachiopods of the Luhui Member of the Dale Formation (late Emsian), Xiangzhou, central Guangxi. *Memoirs of the Nanjing Institute of Geology and Palaeontology* 25: 213–232.
- Chlupáč, I., 1976. The oldest goniatite faunas and their stratigraphical significance. *Lethaia* 9: 303–315.
- COCKS, L. R. M., 1979. New acrotretacean brachiopods from the Palaeozoic of Britain and Austria. *Palaeontology* 22: 93–100.
- COCKS, L. R. M. & RONG JIA-YU, 2000. Strophomenida. In *Treatise on Invertebrate Paleontology, part H, Brachiopoda, revised, volume 2: Linguliformea, Craniiformea, and Rhynchonelliformea (part)*, R. L. Kaesler, ed. Geological Society of America and University of Kansas Press, Lawrence, 216–349.
- CONRAD, T. A., 1842. Observations on the Silurian and Devonian systems of the US with descriptions of new organic remains. *Journal of the Academy of Natural Sciences of Philadelphia* 8: 228–280.
- COPPER, P., 1965. A new Middle Devonian atrypid brachiopod from the Eifel of Germany. *Senckenbergiana lethaea* 46: 309–325.
- COPPER, P., 1966a. European Mid-Devonian correlations. *Nature* 209: 982–984.
- COPPER, P., 1966b. The *Atrypa zonata* brachiopod group in the Eifel, Germany. *Senckenbergiana lethaea* 46: 309–325.
- COPPER, P., 1973. *Bifida* and *Kayseria* (Brachiopoda) and their affinity. *Palaeontology* 16: 117–138.
- COPPER, P., 1978. Devonian atrypoids from western and northern Canada. *Geological Association of Canada Special Papers* 18: 289–331.
- COPPER, P., 1986. Filter-feeding and evolution in early spire-bearing brachiopods. In *Les Brachiopodes fossiles et actuels*, P. R. Racheboeuf & C. C. Emig, eds. *Biostratigraphie du Paléozoïque* 4: 219–230.
- COPPER, P., 1991. Evolution of the atrypid brachiopods. In *Brachiopods Through Time*, D. I. MacKinnon, D. E. Lee & P. J. D. Campbell, eds. A.A. Balkema, Rotterdam, 35–40.
- COPPER, P., 2002. Atrypida. In *Treatise on Invertebrate Paleontology, part H, Brachiopoda, revised, volume 4: Rhynchonelliformea (part)*, R. L. Kaesler, ed. Geological Society of America and University of Kansas Press, Boulder and Lawrence, 1377–1474.
- COPPER, P. & GOURVENNEC, R. 1996. Evolution of the spire-bearing brachiopods (Ordovician–Jurassic). In *Brachiopods*, P. Copper & J. Jin, eds. A.A. Balkema, Rotterdam, 81–88.
- DAGYS, A., 1996. On the classification of the order Athyridida. In *Brachiopods*, P. Copper & J. Jin, eds. A.A. Balkema, Rotterdam, 89–90.
- DALMAN, J. W., 1828. Uppställning och Beskrifning af de i Sverige funne Terebratuliter. *Kongliga Svenska Vetenskapsakademien Handlingar for 1827* 3: 85–155.
- DAVIDSON, T., 1858a. A monograph of the British fossil Brachiopoda: Part 5, Carboniferous. *Palaeontographical Society* 5: 1–280.
- DAVIDSON, T., 1858b. Palaeontological notes on the Brachiopoda, no. 1. On genera and sub-

genera of Brachiopoda that are provided with spiral appendages for the support of the oral arms, and species so constructed, which have been discovered in British Carboniferous strata. *Geologist* 1: 409-416, 457-331.

- DEFRANCE, M. J. L., 1824. *Dictionnaire des Sciences Naturelles* 32: 1-306.
- DE KONINCK, L. G., 1876. Recherches sur les fossiles Paléozoïques de la Nouvelle-Galles du Sud (Australie). *Mémoires du Société Royale des Sciences de Liège* 3: 25-52.
- DE KONINCK, L. G., 1898. Descriptions of the Palaeozoic fossils of New South Wales (Australia). (Translated by T. W. E. David, Mrs David & W. S. Dun from de Koninck 1876). *Memoirs of the Geological Survey of New South Wales, Palaeontology* 6: 1-298.
- D'ORBIGNY, A., 1850. *Prodrome de paléontologie stratigraphie universelle des animaux mollusques et rayonnés*, vol. 1. Victor Mason, Paris, ix+349 pp.
- DROT, J., 1964. Rhynchonelloidea et Spiriferoidea Siluro-Dévonien du Maroc présaharien. *Notes et Mémoires Service Géologique du Maroc* 178: 1-287.
- DUN, W. S., 1904. Notes on some new species of Palaeozoic Brachiopoda from New South Wales. *Records of the Geological Survey of New South Wales* 7: 318-325.
- ERBEN, H. K., 1960. Primitive Ammonoidea aus dem Unterdevon Frankreichs und Deutschlands. *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen* 110: 1-128.
- ERBEN, H. K., 1962. Unterlagen zur Diskussion der Unter/Mitteldevon-Grenze. In *Symposium-Band der 2. Internationalen Arbeitstagung über die Silur/Devon-Grenze und die stratigraphie des Silurs und des Devons* (1960) 315: 62-70.
- ERBEN, H. K., 1964. Die Evolution der ältesten Ammonoidea (Lieferung I). *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen* 120: 107-212.
- ERBEN, H. K., 1965. Die Evolution der ältesten Ammonoidea (Lieferung II). *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen* 122: 275-312.
- FARRELL, J. R., 1992. The Garra Formation (Early Devonian: late Lochkovian) between Cumnoek and Larras Lee, New South Wales, Australia: stratigraphic and structural setting, faunas and community sequence. *Palaontographica Abt. A* 222: 1-41.
- FICHNER, F. & Havlíček, V., 1978. Middle Devonian brachiopods from Čelčovice, Moravia. *Sborník geologických věd palaeontologie* 21: 49-106.
- FOERSTE, A. F., 1917. Notes on Silurian fossils from Ohio and other central states. *Ohio Journal of Science* 17: 233-268.
- FÖLDVARY, G. Z., 2000. Siluro-Devonian invertebrate faunas from the Bogan Gate-Trundle-Mineral Hill area of central New South Wales. *Records of the Western Australian Museum, Supplement* 58: 81-102.
- GEORGE, T. N., 1931. Ambocoelia Hall and certain similar British Spiriferidae. *Quarterly Journal of the Geological Society of London* 87: 30-61.
- GILL, E. D., 1950. Preliminary account of the palaeontology and palaeoecology of the Eldon Group Formations of the Zeehan area, Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 1949: 231-258.
- GILL, E. D., 1951. Two new brachiopod genera from Devonian rocks in Victoria. *Memoirs of the National Museum, Melbourne* 17: 187-205.
- GIRTY, G. H., 1904. New molluscan genera from the Carboniferous. *United States National Museum Proceedings* 27: 721-736.
- GOLDFUSS, A., 1839. Beiträge zur Petrefactenkunde. *Verhandlungen der Kaiserlichen Leopoldinisch-Carolinischen der Naturforscher* 19: 327-364.
- GRATSIANOVA, R. T., 1974. "Shukhertelly" rannego i srednego devona na yuge zapadnoi Sibiri: sistematičeskaja prikladnaja znanost', elementy ekologii stratigraficheskoi značenie. In *Sreda i žizn' v geologičeskom prošlom (paleoekologičeskije problemy)*, O. A. Betekhitina & I. T. Zhuravleva, eds *Akademiia Nauk SSSR, Sibirskoe Otdelenie, Institut Geologii i Geofiziki (IGIG), Trudy* 84: 77-87.
- GÜRICH, G., 1896. Das Paläozoicum Polnischen Mittelgebirge. *Verhandlungen der Russisch-Kaiserliche Mineralogische Gesellschaft zu St. Petersburg* 32: 1-539.
- HALL, J., 1843. Survey of the fourth geological district. *Natural history of New York, Geology*, vol. 4. Carroll & Albany, Albany, ix+525 pp.

- HALL, J., 1857. Descriptions of new species of Palaeozoic fossils from the Lower Helderberg, Oriskany Sandstone, Upper Helderberg, Hamilton and Chemung Groups. *New York State Cabinet of Natural History 10th Annual Report*: 41–186.
- HALL, J., 1859a. Observations on genera of Brachiopoda. Contributions to the palaeontology of New York. *New York State Cabinet of Natural History 12th Annual Report* 8–110.
- HALL, J., 1859b. Containing descriptions and figures of the organic remains of the Lower Helderberg Group and the Oriskany Sandstone. *Natural History of new York, Palaeontology* 3: 1–532.
- HALL, J., 1860. Descriptions of new species of fossils, from the Hamilton group of western New York, with notices of others from the same horizon in Iowa and Indiana. *New York State Cabinet of Natural History 13th Annual Report* 76–94.
- HALL, J., 1863. Contributions to palaeontology. *16th Annual Report of the Regents of the University of the State of New York on the condition of the State Cabinet of Natural History*: 3–226.
- HALL, J. & CLARKE, J. M., 1892. An introduction to the study of the genera of Palaeozoic Brachiopoda. *Palaeontology of New York* 8: 1–367.
- HALL, J. & CLARKE, J. M., 1893. An introduction to the study of the genera of Palaeozoic Brachiopoda. *Palaeontology of New York* 8: 1–317.
- HALL, J. & CLARKE, J. M., 1894. An introduction to the study of the Brachiopoda, intended as a handbook for the use of students. *Thirteenth Annual Report of the New York State Geologist for the Year 1893, Palaeontology* 2: 751–943.
- HARPER, C. W., 1973. Brachiopods of the Arisaig Group (Silurian-Lower Devonian) of Nova Scotia. *Geological Survey of Canada Bulletin* 215: 1–163.
- HARPER, C. W. & BOUCOT, A. J., 1978a. The Strophodontacea, part I: Leptostrophiidae, Eostrophodontidae and Strophonellidae. *Palaeontographica Abt. A* 161: 55–118.
- HARPER, C. W. & BOUCOT, A. J., 1978b. The Strophomenacea, part II: Douvillinidae, Telacoshaleriidae, Amphistrophiidae and Shaleriidae. *Palaeontographica Abt. A* 161: 119–175.
- HARPER, C. W., JOHNSON, J. G. & BOUCOT, A. J., 1967. The Pholidostrophiinae (Brachiopoda; Ordovician, Silurian, Devonian). *Senckenbergiana lethaea* 48: 403–461.
- HARPER, D. A. T., 2000. Dalmanellidina. In *Treatise on Invertebrate Paleontology, part H, Brachiopoda, revised, volume 3: Linguliformea, Craniiformea, and Rhynchonelliformea (part)*. R. L. Kaesler, ed. Geological Society of America and University of Kansas Press, Boulder and Lawrence, 782–844.
- Havlíček, V., 1953. O několika nových ramenonožcích českého a moravského středního devonu. *Věstník Ústředního ústavu geologického* 28: 4–9.
- Havlíček, V., 1956. Ramenonožci vapeneu branických a hluboepejských z nejbližšího pražského okolí. *Sborník Ústředního ústavu geologického* 22: 535–665.
- Havlíček, V., 1959a. Rhynchonelloidea des böhmischen älteren Paläozoikums (Brachiopoda). *Rozprawy Ústředního ústavu geologického* 27: 1–211.
- Havlíček, V., 1959b. Spiriferidae v českém siluru a devonu (Brachiopoda). *Rozprawy Ústředního ústavu geologického* 25: 1–219.
- Havlíček, V., 1967. Brachiopoda of the suborder Strophomenidina in Czechoslovakia. *Rozprawy Ústředního ústavu geologického* 33: 1–235.
- Havlíček, V., 1975. New genera and species of Orthida (Brachiopoda). *Věstník Ústředního ústavu geologického* 50: 231–235.
- Havlíček, V., 1977. Brachiopods of the order Orthida in Czechoslovakia. *Rozprawy Ústředního ústavu geologického* 44: 1–327.
- HILL, D., 1950. Middle Devonian corals from the Buchan district, Victoria. *Proceedings of the Royal Society of Victoria* 62: 137–164.
- HILL, D., PLAYFORD, G. & WOODS, J. T., 1967. *Devonian Fossils of Queensland*. Queensland Palaeontographical Society, Brisbane, 32 pp.
- HOLLOWAY, D. J., 1996. New Early Devonian styginid trilobites from Victoria, Australia, with revision of some spinose styginids. *Journal of Paleontology* 70: 428–438.
- HOLMER, L. E. & POPOV, L. E. 2000. Lingulata. In *Treatise on Invertebrate Paleontology*,

- part H, *Brachiopoda*, revised, volume 2: *Linguliformea*, *Craniiiformea*, and *Rhynchonelliformea* (part), R. L. Kaesler, ed. Geological Society of America and University of Kansas Press, Boulder and Lawrence, 30–146.
- HOU HONG-FEI & XIAN SI-YUAN, 1975. The Lower and Middle Devonian brachiopods from Guangxi and Guizhou. *Professional Papers of Stratigraphy and Palaeontology* 1: 1–85.
- HOUSE, M. R., 1979. Biostratigraphy of the early Ammonoidea. In *The Devonian System*, M. R. House, C. T. Scrutton & M. G. Bassett, eds. *Special Papers in Palaeontology* 23: 263–280.
- HOWITT, A. W., 1876. Notes on the Devonian rocks of northern Gippsland. *Geological Survey of Victoria, Progress Report* 3: 181–249.
- ICZN, 1956. Opinion 420. Addition to the "Official List of Specific Names in Zoology" of the specific names for eleven species of the Class Brachiopoda and for 2 species of the Class Cephalopoda originally published by Martin (W.) in 1809 in the nomenclatorially invalid work entitled "Petrificata Derbiensia" and now available as from the first subsequent date on which they were severally published in conditions satisfying the requirements of the "Regles". *Opinions and Declarations Rendered by the International Commission on Zoological Nomenclature* 14: 131–167.
- JOHNSON, J. G., 1970a. Great Basin Lower Devonian Brachiopoda. *Memoir of the Geological Society of America* 121: 1–421.
- JOHNSON, J. G., 1970b. Early Middle Devonian brachiopods from central Nevada. *Journal of Paleontology* 44: 252–264.
- JOHNSON, J. G., 1971. Some new and problematical brachiopods from the Lower Devonian of Nevada. *Journal of Paleontology* 45: 95–99.
- JOHNSON, J. G., 1974a. Middle Devonian Givetian brachiopods from the *Leiorhynchus castanea* Zone of Nevada. *Geologica et Palaeontologica* 8: 49–96.
- JOHNSON, J. G., 1974b. Affinity of Dayiacean brachiopods. *Palaentology* 17: 437–439.
- JOHNSON, J. G. & BOUCOT, A. J., 1968. External morphology of *Anatrypa* (Devonian, Brachiopoda). *Journal of Paleontology* 42: 1205–1207.
- JOHNSON, J. G., BOUCOT, A. J. & MURPHY, M. A., 1973. Pridolian and Early Gedinnian age brachiopods from the Roberts Mountains Formation of Central Nevada. *University of California Publications in Geological Science* 100: 1–75.
- JOHNSON, J. G. & TALENT, J. A., 1967. *Muriferella*, a new genus of Lower Devonian septate Dalmanellid. *Proceedings of the Royal Society of Victoria* 80: 43–50.
- JOHNSTON, P. A., 1993. Lower Devonian Pelecypoda from southeastern Australia. *Memoirs of the Association of Australasian Palaeontologists* 14: 1–134.
- KAESLER, R. L. ed., 2000. *Treatise on Invertebrate Palaeontology, part H, Brachiopoda, revised, volumes 2–3: Linguliformea, Craniiiformea, and Rhynchonelliformea (part)*. Geological Society of America and University of Kansas Press, Boulder and Lawrence, xxx+ii+919 pp.
- KAESLER, R. L. ed., 2002. *Treatise on Invertebrate Palaeontology, Part H, Brachiopoda, revised, volume 4: Rhynchonelliformea (part)*. Geological Society of America and University of Kansas Press, Boulder and Lawrence, xxxix+767 pp.
- KAPLUN, L. I. & KRUPCHENKO, N. V., 1991. Brachipody nizhnego i srednego devona Dzhungaro-Balkhashskoi provintsii. In *Biostratigrafiia nizhnego i srednego devona Dzhungaro-Balkhashskoi provintsii*, V. N. Dubatolov & G. A. Stukalina, eds. Nauka, Novosibirsk, 111–147.
- KAYSER, E., 1871. Die Brachiopoden aus Mittel- und Ober-Devon der Eifel. *Zeitschrift der Deutschen Geologischen Gesellschaft* 23: 491–647.
- KOZŁOWSKI, R., 1929. Les brachiopodes gothlandiens de la Podolie Polonaise. *Palaeontologia Polonica* 1: 1–254.
- KOZŁOWSKI, R., 1946. *Howellella*, a new name for *Crispella* Kozłowski, 1929. *Journal of Paleontology* 20: 295.
- KRAUSE, F. F. & ROWELL, A. J., 1975. Distribution and systematics of the inarticulate brachiopods of the Ordovician carbonate mud mound of Meiklejohn Peak, Nevada. *University of Kansas Paleontological Contributions Paper* 61: 1–74.
- LAMARCK, J. B. P., 1819. *Historie Naturelle des Animaux sans Vertèbres, part 1. Brachiopoda*. J. B. Baillière, Paris, 735 pp.

- LENZ, A. C., 1977a. Upper Silurian and Lower Devonian brachiopods of Royal Creek, Yukon, Canada. Part 1: Orthoidea, Strophomenida, Pentamerida, Rhynchonellida. *Palaeontographica Abt. A* 159: 37–109.
- LENZ, A. C., 1977b. Upper Silurian and Lower Devonian brachiopods of Royal Creek, Yukon, Canada. Part 2: Spiriferida: Atrypacea, Dayiacea, Athyridacea, Spiriferacea. *Palaeontographica Abt. A* 159: 111–138.
- LENZ, A. C. & JOHNSON, B. D., 1985a. Brachiopods of the Garra Formation (Lower Devonian), Wellington area, New South Wales, Australia: Orthoidea, Strophomenida, Pentamerida. *Palaeontographica Abt. A* 188: 35–70.
- LENZ, A. C. & JOHNSON, B. D., 1985b. Brachiopods of the Garra Formation (Lower Devonian), Wellington area, New South Wales, Australia: Rhynchonellida, Spiriferida, Terebratulida. *Palaeontographica Abt. A* 188: 71–104.
- LONG, J. A., 1984. New Placoderm fishes from the Early Devonian Buchan Group, eastern Victoria. *Proceedings of the Royal Society of Victoria* 96: 173–186.
- LONG, J. A., 1986. New ischnacanthid acanthodians from the Early Devonian of Australia, with comments on acanthodian interrelationships. *Zoological Journal of the Linnean Society* 87: 321–339.
- LUDVIGSEN, R., 1974. A new Devonian acrotretid (Brachiopoda, Inarticulata) with unique protegular ultrastructure. *Neues Jahrbuch für Geologie und Paläontologie Monatshefte* 3: 133–148.
- MAURER, F., 1889. Palaeontologische studien in gebeit des Rheinischen Devon. 8 Mittheilungen über fauna gliederung des Reehsrheinischen Unterdevon. *Neues Jahrbuch für Mineralogie Abhandlungen* 2: 1–160.
- MAWSON, R., 1987. Early Devonian conodont faunas from Buchan and Bindi, Victoria, Australia. *Palaeontology* 30: 251–297.
- MAWSON, R. & TALENT, J. A., 1999. Early Devonian (Lochkovian) brachiopods from Windellama, southeastern Australia. *Senckenbergiana lethaea* 79: 145–189.
- MAWSON, R. & TALENT, J. A., 2000. The Devonian of eastern Australia: stratigraphic alignments, stage and series boundaries, and the transgression-regression pattern re-considered. In Subcommission on Devonian stratigraphy: recognition of Devonian series and stage boundaries in geological areas, P. Bultynck, ed. *Courier Forschungsinstitut Senckenberg* 225: 243–270.
- MAWSON, R., TALENT, J. A., BEAR, V. C., BENSON, D. S., BROCK, G. A., FARRELL, J. R., HYLAND, K. A., PYEMONT, B. D., SLOAN, T. R., SORENTINO, L., STEWART, M. I., TROTTER, J. A., WILSON, G. A. & SIMPSON, A. G., 1988. Conodont data in relation to resolution of stage and zonal boundaries for the Devonian of Australia. In Devonian of the world; proceedings of the second international symposium on the Devonian System; volume III, paleontology, paleoecology and biostratigraphy, N. J. McMillan, A. F. Embry & D. J. Glass, eds. *Memoir of the Canadian Society of Petroleum Geologists* 14: 485–527.
- MAWSON, R., TALENT, J. A., BROCK, G. A. & ENGELBRETSSEN, M. J., 1992. Conodont data in relation to sequences about the Pragian-Emsian boundary (Early Devonian) in southeastern Australia. *Proceedings of the Royal Society of Victoria* 104: 23–56.
- MCCOY, F., 1867. On the recent zoology and palaeontology of Victoria. *Annals and Magazine of Natural History* 20: 175–202.
- MCCOY, F., 1876. *Prodromus of the Palaeontology of Victoria* Decade 4: 15–20.
- MERGL, M., 2001. Lingulate brachiopods of the Silurian and Devonian of the Barrandian (Bohemia, Czech Republic). *Acta Musei Nationalis Pragae, Series B, Historia Naturalis* 57: 1–49.
- MITCHELL, J. & DUN, W. S., 1920. The Atrypidae of New South Wales, with reference to those recorded from other states of Australia. *Proceedings of the Linnean Society of New South Wales* 45: 266–276.
- MUIR-WOOD, H. M., 1925. Notes on the Silurian brachiopod genera *Delthyris*, *Uncinulina*, and *Meristina*. *Annals and Magazine of Natural History* 15: 83–95.
- MUIR-WOOD, H. M., 1962. *On the morphology and classification of the brachiopod suborder Chonetoida*. British Museum (Natural History), London, viii+132 pp.

- MURCHISON, R. I., 1839. *The Silurian system founded on geological researches in the counties of Salop, Hereford, Radnor, Montgomery, Caerthmarthen, Brecon, Pembroke, Monmouth, Gloucester, Worcester, and Stafford: with descriptions of the coalfields and overlying formations*. John Murray Publishers, London, xxxiii+768 pp.
- PAJCHLOWA, M., 1957. Devon w profilu Grzegorzowice-Skaly. *Biuletyn Instytutu Geologicznego* 122: 145–254.
- PARFREY, S. M., 1989. Early Devonian fossils from the Ukalunda Beds northwest of Mount Coolon, central Queensland. *Queensland Government Mining Journal* 90: 20–21.
- PERRY, D. G., 1979. Late Early Devonian reef associated brachiopods of the Prongs Creek Formation, northern Yukon. *Journal of Paleontology* 53: 1094–1111.
- PERRY, D. G., 1984. Brachiopoda and biostratigraphy of the Silurian-Devonian Delorme Formation in the district of Mackenzie, the Yukon. *Royal Ontario Museum Life Science Contributions* 138: 1–243.
- PHILIP, G. M., 1962. The palaeontology and stratigraphy of the Siluro-Devonian sediments of the Tyers area, Gippsland, Victoria. *Proceedings of the Royal Society of Victoria* 75: 123–246.
- PHILIP, G. M., 1966. Lower Devonian conodonts from the Buchan Group, eastern Victoria. *Micropaleontology* 12: 441–460.
- PHILIP, G. M. & PEDDER, A. E. H., 1964. A re-assessment of the age of the Middle Devonian of south-eastern Australia. *Nature* 202: 1323–1324.
- POPOV, L. E., 1981a. Pervaja nakhodka bez-zamkovykh brakhiopod semeistva Aerotretidae v nizhnem devone SSSR. In *Paleontologicheskii osnovna stratigraficheskikh skliem paleozoia mezozoia ostrovo Sovetskoi Arktiki*, V. I. Bondarev, ed. Leningrad, 61–65.
- POPOV, L. E., 1981b. Pervaja nakhodka mikroskopicheskikh bezzamkovykh brakhiopod semeistva Aerotretidae v silure Estonii. *Eesti NSV Teaduste Akadeemia Toimetised (Geologia)* 30: 34–41.
- POPOV, L. E., NÖLVAK, J. & HOLMER, L. E., 1994. Late Ordovician lingulate brachiopods from Estonia. *Palaeontology* 37: 627–650.
- PUSCH, G. G., 1833. *Geognostische Beschreibung von Polen, so wie der übrigen Nord-karpathen-Länder. Part 1*. Stuttgart & Tübingen, 338 pp.
- PYEMONT, B. D., 1990. *Conodont faunal succession through the Murrindal Limestone, Buchan area, Victoria*. MSc thesis, Macquarie University, Sydney (unpubl.).
- QUENSTEDT, F. A., 1868–1871. *Petrefactenkunde Deutschlands. Die Brachiopoden* 2: 1–748.
- RACHEBOEUF, P. R., 1987. Upper Lower and lower Middle Devonian chonetacean brachiopods from Bathurst, Devon and Ellesmere Islands, Canadian Arctic Archipelago. *Geological Survey of Canada Bulletin* 375: 1–29.
- REED, F. R. C., 1908. The Devonian faunas of the northern Shan States. *Palaeontologica Indica* 2: 1–183.
- RONG JIA-YU & COCKS, L. R. M., 1994. True Strophomena and a revision of the classification and evolution of strophomenoid and 'strophodontoid' brachiopods. *Palaeontology* 37: 651–694.
- RZIONSNIISKAYA, M. A., 1975. Biostratigraphia devona okrain Kuznetskogo basseina. Tom 2: Opisani brakhiopod, Chast' 1: Pentamerida i Atrypida. *Trudy Vsesoiuznyi Ordena Lenina Nauchno-issledovatel'skii Geologicheskii Institut* 244: 1–232.
- SAVAGE, N. M., 1968. Planicardinia, a new septate dalmanellid brachiopod from the Devonian of New South Wales. *Palaeontology* 11: 627–632.
- SAVAGE, N. M., 1969. New spiriferid brachiopods from the Lower Devonian of New South Wales. *Palaeontology* 12: 472–487.
- SAVAGE, N. M., 1971. Brachiopods from the Lower Devonian Mandagery Park Formation, New South Wales. *Palaeontology* 14: 387–422.
- SAVAGE, N. M., 1974. The brachiopods of the Lower Devonian Maradana Shale, New South Wales. *Palaeontographica Abt. A* 146: 1–51.
- SAVAGE, N. M., 1981. A reassessment of the age of some Paleozoic brachiopods from south-eastern Alaska. *Journal of Paleontology* 55: 353–369.
- SCHINDEWOLF, O. H., 1932. Zur Stammesgeschichte der Ammonoiten. *Paläontologische Zeitschrift* 14: 164–181.

- SCHNUR, J. 1853. Zusammenstellung und Beschreibung sämtlicher im Übergangsgebirge der Eifel vorkommenden Brachiopoden, nebst Abbildungen Derselben. *Palaeontographica* 3: 169–257.
- SCHUCHERT, C. & COOPER, G. A., 1931. Synopsis of the brachiopod genera of the suborders Orthoidea and Pentamerioidea, with notes on the Telotremita. *American Journal of Science (Series 5)* 22: 214–255.
- SCHUCHERT, C. & COOPER, G. A., 1932. Brachiopod genera of the suborders Orthoidea and Pentamerioidea. *Memoirs of the Peabody Museum of Natural History* 4: 1–270.
- SELWYN, A. R. C. & ULRICH, G. H. F., 1867. Notes on the physical geography, geology and mineralogy of Victoria. *Intercolonial Exhibition of Australasia, Melbourne 1866–67* 3: 147–235.
- SHERWIN, L., 1995. Siluro-Devonian brachiopods from the Amphitheatre and Winduck Groups (Cobar Supergroup), western New South Wales. *Memoirs of the Association of Australasian Palaeontologists* 18: 61–96.
- SMITH, R. E., 1980. Lower Devonian (Lochkovian) biostratigraphy and brachiopod faunas, Canadian Arctic Islands. *Geological Survey of Canada Bulletin* 308: 1–155.
- SOJA, C. M., 1988. Lower Devonian (Emsian) brachiopods from southeastern Alaska, U.S.A. *Palaeontographica Abt. A* 201: 129–193.
- SOWERBY, J., 1822. *The mineral conchology of Great Britain*, vol. 4. Published by the author, London, 114 pp.
- SPRIESTERSBACK, J. & FUCHS, A., 1909. Die fauna der Remscheider Schichten. *Abhandlungen Preussischen Geologischen Landesanstalt* 58: 1–81.
- STRUSZ, D. L., 1982. Wenlock brachiopods from Canberra, Australia. *Alcheringa* 6: 105–142.
- STRUSZ, D. L., 1990. Catalogue of type, figured and cited specimens in the Commonwealth palaeontological collection: Brachiopoda. *Bureau of Mineral Resources, Geology and Geophysics Report* 298: 1–289.
- STRUSZ, D. L., 2000. Revision of the Silurian and Early Devonian ehnetoidean brachiopods of southeastern Australia. *Records of the Australian Museum* 52: 245–287.
- STRUSZ, D. L., CHATTERTON, B. D. E. & FLOOD, P. G., 1970. Revision of the New South Wales Devonian Brachiopod ‘*Spirifer*’ *yassensis*. *Proceedings of the Linnean Society of New South Wales* 95: 170–190.
- SUSSMILCH, C. A., 1914. *An Introduction to the Geology of New South Wales*, 2nd edn. Angus & Robertson, Sydney, 296 pp.
- SUSSMILCH, C. A., 1922. *An Introduction to the Geology of New South Wales*, 3rd edn. Angus & Robertson, Sydney, 296 pp.
- TALENT, J. A., 1956a. Devonian brachiopods and pelecypods of the Buchan Caves Limestone, Victoria. *Proceedings of the Royal Society of Victoria* 68: 1–56.
- TALENT, J. A., 1956b. Siluro-Devonian brachiopods from Marble Creek, Thompson River, Victoria. *Proceedings of the Royal Society of Victoria* 68: 73–84.
- TALENT, J. A., 1963. The Devonian of the Mitchell and Wentworth Rivers. *Memoirs of the Geological Survey of Victoria* 24: 1–118.
- TALENT, J. A., 1965a. The stratigraphic and diastrophic evolution of central and eastern Victoria in Middle Palaeozoic times. *Proceedings of the Royal Society of Victoria* 79: 175–195.
- TALENT, J. A., 1965b. The Silurian and Early Devonian faunas of the Heathcote District, Victoria. *Memoirs of the Geological Survey of Victoria* 26: 1–55.
- TALENT, J. A., 1969. The geology of east Gippsland. *Proceedings of the Royal Society of Victoria* 82: 37–60.
- TALENT, J. A., GRATSIANOVA, R. T. & YOLKIN, E. A., 2001. Latest Silurian (Pridoli) to Middle Devonian of the Asia-Australia hemisphere: rationalization of brachiopod taxa and faunal lists; correlation charts. *Courier Forschungsinstitut Senckenberg* 236: 1–221.
- TALENT, J. A., MAWSON, R., AITCHISON, J. C., BECKER, R. T., BELL, K. N., BRADSHAW, M. A., BURROW, C. J., COOK, A. G., DARGAN, G. M., DOUGLAS, J. G., EDGECOMBE, G. D., FEIST, M., JONES, P. J., LONG, J. A., PHILLIPS-ROSS, J. R., PICKETT, J. W., PLAYFORD, G., RICKARDS, R. B., WEBBY, B. D., WINCHESTER-SEETO, T., WRIGHT, A. J., YOUNG, G. C. & ZHEN YONG-YI, 2000. Devonian palaeobiogeography of Australia and adjoining regions. In *Palaeobio-*

- geography of Australasian faunas and floras, A. J. Wright, G. C. Young, J. A. Talent & J. R. Laurie, eds. *Memoir of the Association of Australasian Palaeontologists* 23: 167–257.
- TEICHERT, C., 1948. Middle Devonian goniatites from the Buchan district, Victoria. *Journal of Palaeontology* 22: 60–67.
- TEICHERT, C. & TALENT, J. A., 1958. Geology of the Buchan area, east Gippsland. *Memoirs of the Geological Survey of Victoria* 21: 1–52.
- TIEN, C. C., 1938. Devonian Brachiopoda of Hunan. *Palaeontologia Sinica* 4: 1–192.
- VALENTINE, J. L., BROCK, G. A. & MOLLOY, P. D., 2003. Linguliformean brachiopod faunal turnover across the Ireviken Event (Silurian) at Boree Creek, central-western New South Wales, Australia. *Conrrier Forschungsinstitut Senckenberg* 242: 301–327.
- VANDERCAMMEN, A., 1963. Spiriferidae du Dévonien de la Belgique. *Institut Royal des Sciences Naturelles de Belgique, Mémoires* 150: 1–179.
- VEEVERS, J. J., 1959. Devonian brachiopods from the Fitzroy Basin, Western Australia. *Bureau of Mineral Resources, Geology and Geophysics Bulletin* 45: 1–220.
- VON BITTER, P. H. & LUDVIGSEN, R., 1979. Formation and function of protegular pitting in some North American acrotretid brachiopods. *Palaeontology* 22: 705–720.
- VON MEYER, H., 1831. Beschreibung des *Orthoceratites striolatus* und über den bau und das Vorkommen einiger vielkammeriger fossiler Cephalopoden, nebst Beschreibung von *Calymene aequalis*. *Vernhandlungen der Leopoldinisch-Carolinisch Akademie der Naturforschende* 15: 59–112.
- WALCOTT, C. D., 1884. Paleontology of the Eureka District. *United States Geological Survey Monographs* 8: 1–298.
- WALLACE, M., 1987. The role of internal erosion and sedimentation in the formation of stromatolite mudmounds and associated lithologies. *Journal of Sedimentary Petrology* 57: 695–700.
- WALMSLEY, V. G. & BOUCOT, A. J., 1971. The Resserellinae—a new subfamily of Late Ordovician to Devonian dalmanellid brachiopods. *Palaeontology* 14: 487–531.
- WALMSLEY, V. G. & BOUCOT, A. J., 1975. The phylogeny, taxonomy and biogeography of Silurian and Early to mid-Devonian Isorthisinae (Brachiopoda). *Palaeontographica Abt. A* 148: 34–108.
- WANG YÜ, 1956. Some new brachiopods from the Yükiang Formation of Southern Kwangsi Province. *Scientia Sinica* 5: 373–388.
- WANG YÜ & RONG JIA-YU, 1986. Early Emsian (Devonian) brachiopods of the Nanning-Liujing district, central Guangxi, southern China. *Palaeontologia Sinica* 172: 1–282.
- WANG YÜ, RONG JIA-YU & CHEN XIU-QIN, 1987. Early late Emsian brachiopods from Dale, Xiangzhou, Guangxi. *Memoirs of the Nanjing Institute of Geology and Palaeontology* 23: 121–146.
- WANG YÜ, YÜ CHIANG-MING & WU QI, 1974. Advances in the Devonian biostratigraphy of south China. *Memoirs of the Nanjing Institute of Geology and Palaeontology* 6: 1–71.
- WEBBY, B. D., STEARN, C. W. & ZHEN YONG-YI, 1993. Lower Devonian (Pragian-Emsian) stromatoporoids from Victoria. *Proceedings of the Royal Society of Victoria* 105: 113–185.
- WHITEHOUSE, F. W., 1929. Preliminary report on Devonian fossils from the districts of Mt Wyatt and Ukalunda. *Queensland Government Mining Journal* 30: 158–159.
- WILLIAMS, A. & BRUNTON, C. H., 1993. Role of shell structure in the classification of the orthotetidine brachiopods. *Palaeontology* 36: 931–966.
- WILLIAMS, A. & HARPER, D. A. T., 2000. Orthida. In *Treatise on Invertebrate Paleontology, part H, Brachiopoda, revised, volume 3: Linguliformea, Craniiformea, and Rhynchonelliformea (part)*, R. L. Kaesler, ed. Geological Society of America and University of Kansas Press, Boulder and Lawrence, 714–844.
- WINCHESTER-SEETO, T. M., 1996. Emsian Chitinozoa from the Buchan area of southeastern Australia. *Acta Palaeontologica Polonica* 41: 149–230.
- WINCHESTER-SEETO, T. M. & PARIS, F., 1989. Preliminary investigations of some Devonian (Lochkovian-Eifelian) chitinozoans from eastern Australia. *Alcheringa* 13: 167–173.

XU HAN-KUI, 1987. Lower Devonian brachiopods from Xainza, northern Xizang. *Bulletin of the Nanjing Institute of Geology and Palaeontology* 11: 21-62.

ZHANG NING, 1989. Wenlockian (Silurian) brachiopods of the Cape Phillips Formation, Baillie Hamilton Island, Arctic Canada: part 1. *Palaeontographica Abt. A* 206: 49-97.

CONODONTS FROM THE WOMBAT CREEK GROUP AND "WIBENDUCK LIMESTONE" (SILURIAN) OF EASTERN VICTORIA

JOHN A. TALENT, ANDREW J. SIMPSON, PETER D. MOLLOY & RUTH MAWSON

Macquarie University Centre for Ecostratigraphy and Palaeobiology, Macquarie University 2109, Australia. E-mail: john.talent@mq.edu.au; asimpson@els.mq.edu.au

J.A. TALENT, A.J. SIMPSON, P.D. MOLLOY & R. MAWSON, R., 2005. Conodonts from the Wombat Creek Group and "Wibenduck Limestone" (Silurian) of eastern Victoria. *Proceedings of the Royal Society of Victoria* 115 (1): 265–291 ISSN 0035-9211.

Conodonts from four carbonate occurrences in the Wombat Creek Group — of the Wombat Creek Graben — a unit closely associated with the "type locality" of the inferred Benambran Orogeny, demonstrate that it includes horizons at least as old as *celloni* Zone (Early Silurian, late Llandovery, Telychian) as well as latest Silurian (Přídolí). Two and possibly three of the most prominent Wombat Creek Group limestones align chronologically with two of the oldest carbonate intervals of the Enano Group (of the Limestone Creek Half-graben) farther east in Victoria, specifically the Lobelia and Farquhar limestones. They also align chronologically with portion of the McCarty's limestone on the right flank of the Indi (= upper Murray) River in southeast New South Wales. The last of these documents carbonate sedimentation commencing earlier, in the early Llandovery (Rhuddanian). The youngest of the four Wombat Creek Group carbonate occurrences to have produced conodonts, Pyle's limestone deposit, is tectonically problematic, but its age is Přídolí (latest Silurian). The Wombat Creek Group and Enano Group sedimentation (and flanking "lost" carbonate platform accumulations) thus appear to have extended through most of Silurian time, from Llandovery to somewhere close to the Silurian–Devonian boundary. The Silurian sedimentary packages of the Wombat Creek Graben and Limestone Creek Half-graben have been regarded as developmentally discrete, but salient similarities in depositional sequence and in chronologic alignments are consistent with them being now-disjunct portions of a formerly continuous sedimentary accumulation, i.e. their preservation in separate tracts may be an artifact of post-depositional tectonics.

Conodont data from an isolated occurrence, the "Wibenduck Limestone", indicate probable mid-Ludlow age (probable latest Gorstian to earliest Ludfordian). It consists of limestone elasts and olistoliths and possibly equates with submarine fans of Lochkovian age elsewhere, such as the Sharpeningstone Conglomerate of the Yass area, southern New South Wales.

Keywords: Victoria, Silurian, Wombat Creek Group, Enano Group, "Wibenduck Limestone", conodonts, Benambran Orogeny

LIMESTONES, long regarded as Late Silurian in age, occur at many horizons in the Wombat Creek Group, a unit outcropping in the valley of the Mitta Mitta River and adjacent parts of the watersheds of the Gibbo River and of the Wombat and Morass Creeks of eastern Victoria (Stirling 1887, 1888b; Ferguson 1899; Chapman 1912; Thomas 1954; Whitelaw 1954; Talent 1959; Bolger 1982; VandenBerg et al. 1998a, 2000). Rocks of broadly similar age, known as the Enano Group, outcrop in the watersheds of the Indi, upper Buchan and upper Tambo rivers about 40–50 km farther east (Whitelaw 1954; VandenBerg et al. 1984; Allen 1987, 1988, 1991, 1992; Simpson & Talent 1995, 1996; Talent et al. 2003a) — for broad location see lower part of Fig. 1. It has been demonstrated (Simpson & Talent 1995) that the age-spectrum represented by the limestones and other calcareous sediments of the

Enano Group equate with most of Silurian time — Llandovery (Aeronian and possibly late Rhuddanian) to Přídolí. Despite the abundance of limestone bodies in the Wombat Creek Group, no compelling data have been presented as to the age-spectrum represented by carbonate bodies and calcareous intervals of the latter. In this report, we provide conodont data bearing on this lacuna.

Opinions diverge regarding the environments of deposition of the Wombat Creek and Enano Groups, some authors regarding all carbonate bodies and calcareous intervals to be allochthonous (VandenBerg et al., 2000), others (principally ourselves) opining that both allochthonous and essentially autochthonous carbonate occurrences are represented. Regardless of the viewpoint advocated, it should be emphasised that most exposures of carbonate bodies and calcareous intervals in both regions are poor,

leading to uncertainty regarding relationships to nearby non-calcareous sediments of most but not all limestone occurrences.

The "Wibenduck Limestone", previously regarded as autochthonous (VandenBerg 1988; VandenBerg et al. 1992, 2000), is regarded as consisting of clasts and olistoliths of various carbonate lithologies, lithified before cannibalisation and subsequent deposition at the top of the Sardine Conglomerate fan deposit; its continued use as a discrete formation is not recommended. A probable latest Gorstian–earliest Ludfordian age is indicated for the "Wibenduck Limestone" materials (see below).

The age-span represented by the Wombat Creek Group has special relevance as regards the Benambran Orogeny as it occurs in what may be termed the "type area" for the latter (Andrews 1938; Browne 1947). But the previously available poor age-constraints on the Wombat Creek Group and, by extension, the onset of the Benambran orogenic event (or events) in that area has led some authors to propose that it is a senior synonym of the "Quidongan Orogeny" (Crook et al. 1973; Ramsay & VandenBerg 1986), an event based, incidentally, on a very local and arguably regionally insignificant unconformity (authors' observations) within the Silurian sequence at Quidong in southeastern New South Wales. The latter unconformity occurs between the Merriangah Siltstone (age determined by graptolites as lying between the late Llandovery *Monograptus crenulatus* and *M. crispus* zones), a distal flysch sequence, and the overlying Quidong Limestone. The precise time-slice within the Wenlock–Ludlow represented by the Quidong Limestone is presently under investigation by R. Parkes (pers. comm.). Of greater sedimentary-tectonic significance at Quidong, in our view, is the Tombong Beds — a thick proximal flysch sequence — resting with profound unconformity on the Late Ordovician Bombala Beds and passing upwards with decrease in arenites into the aforementioned late Llandovery Merriangah Siltstone.

Our observations at Quidong, we emphasise, do not preclude age- and sedimentary-tectonic inferences from unconformities and patterns of sedimentation in Llandovery–Wenlock sequences elsewhere in eastern Australia, but need to be taken into account in evaluating data bearing on "Benambran events" throughout eastern Australia, including resolving questions of diachronism — for which presently available data are far from adequate.

The question of the ages and allochthonicity or otherwise of the limestone bodies in the Mitta Mitta River–Gibbo River–Wombat Creek region (VandenBerg 1998a; VandenBerg et al. 2000) is relevant with regard to dating associated strata and for inferences regarding the time-span to be accorded the Benambran orogenic cycle/cycles in this, its "type locality". Accordingly, before and after filling of the Dartmouth Dam, we extensively sampled most of the major occurrences of limestones in the Wombat Creek Group, and undertook additional sampling of limestones in the Enano Group of the Limestone Creek Half-graben — in quest of data additional to what we presented earlier for the Enano Group (Simpson & Talent 1995) — as well as sampling of the "Wibenduck Limestone".

Below we present conodont data from three limestone occurrences in the Mitta Mitta River–Gibbo River–Wombat Creek area (numbered 1–3 on Fig. 2;), from the small occurrence known as Pyle's limestone deposit near Benambra, and from the "Wibenduck Limestone" farther east (Fig. 1 and 2; see Appendix for locality data), and discuss the age and environmental significance of these occurrences.

CONODONT FAUNAS AND AGES

1. "Lower Mitta" limestone (Loc. 1 — see Appendix)

Low diversity but chronologically interesting faunas were obtained from the "Lower Mitta" limestone on the right flank of the Mitta Mitta River (Table 1). *Ozarkodina cadiaensis* has been reported previously from only three locations in southeastern Australia. These are an unnamed subsurface limestone in the Cadia Mine area about 20 km southwest of Orange (PC 402 of Bischoff 1986; see also Packham et al. 1999), low in the Boree Creek Formation (B5 of Bischoff 1986) and the Lobelia limestone lens adjacent to the Reedy Creek Fault in eastern Victoria (Simpson & Talent 1995: fig. 4). From the associated fauna of PC 402, Bischoff argued that *O. cadiaensis* was restricted to the latest Llandovery to earliest Wenlock *amorphognathoides* Zone. Simpson & Talent (1995: 93) in discussing the age of the Lobelia limestone lens argued that the lower range of the taxon could possibly be construed as of *celoni* Zone age. This was based on unillustrated associated faunas low in the Boree Creek Formation

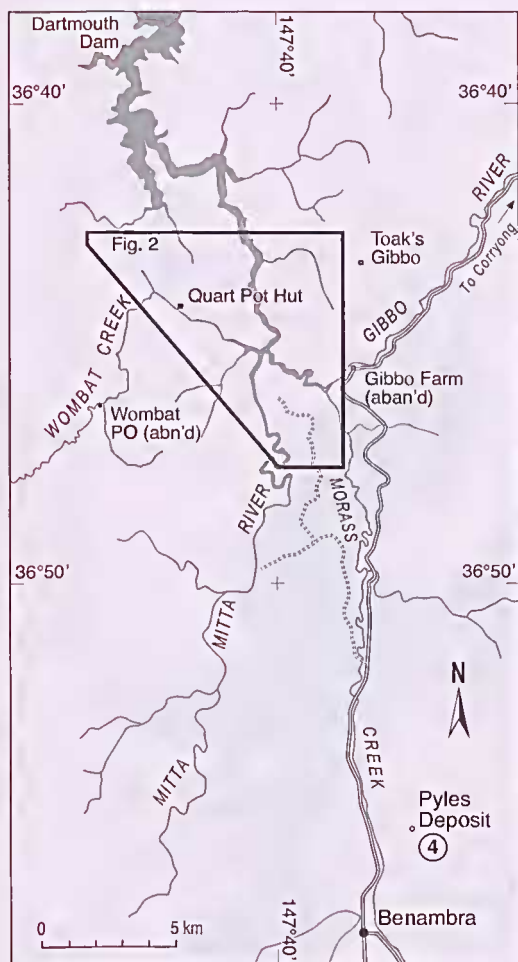


Fig. 1. Location of Fig. 2, and location of Mitta Mitta River-Gibbo River-Wombat Creek region in relation to eastern Victoria.

tabulated by Bischoff (1986) as *Pterospathodus amorphognathoides* that could possibly be interpreted as pennate forms of *Pterospathodus celloni* *sensu* Männik & Aldridge (1989; see also Männik 1998). New data from the Boree Creek Formation of east-central New South Wales are likely to shed further light on the lower limit of the *amorphognathoides* Zone in this unit (Molloy in prep.), but from published data it is reasonable to construe the range of *O. cadiaensis* as broadly late Llandovery to earliest Wenlock *celloni* and *amorphognathoides* zones. The taxon, incidentally, was noticeably absent in a recent report on the fauna of an *amorphognathoides* Zone carbonate unit in the Cadia region (Rickards et al. 2001). Simpson & Talent (1995: 142) have noted that this taxon appears to be ecologically constrained.

The occurrence of Pa elements of *Ozarkodina australensis*, an Sc element of the genus *Distomodus* herein interpreted as *D. stauognathoides*, and the coniform *Panderodus* taxa generally accord with a *celloni* to *amorphognathoides* zone age for the "Lower Mitta" limestone. This unit can therefore be correlated with the upper parts of the lower Claire Creek limestone unit, the upper parts of the McCarty's limestone and it can be broadly correlated with both the Lobelia and Farquar limestones in the Limestone Creek region (Simpson & Talent 1995).

2. Brammall Bluff, Gibbo River (Loc. 2 — see Appendix)

The small conodont fauna recovered from this unit includes elements of the ubiquitous Early Silurian taxon *Distomodus stauognathoides* and the more chronologically restricted *Ozarkodina cadiaensis*. A late Llandovery to earliest Wenlock *celloni* and *amorphognathoides* zones age-range, broadly equivalent with the "Lower Mitta" limestone discussed above, is therefore indicated. A single element of the coniform taxon *Pseudobelodella sibirica* was also recovered. Armstrong (1990: 111) records *P. sibirica* from the Lafayette Bugt Formation of Greenland and suggests this monospecific genus is restricted to the upper *celloni* and *amorphognathoides* zones. This unit can therefore also be correlated with the upper parts of the lower Claire Creek limestone unit, the upper parts of the McCarty's limestone and broadly correlated with both the Lobelia and Farquar limestones (Simpson & Talent 1995).

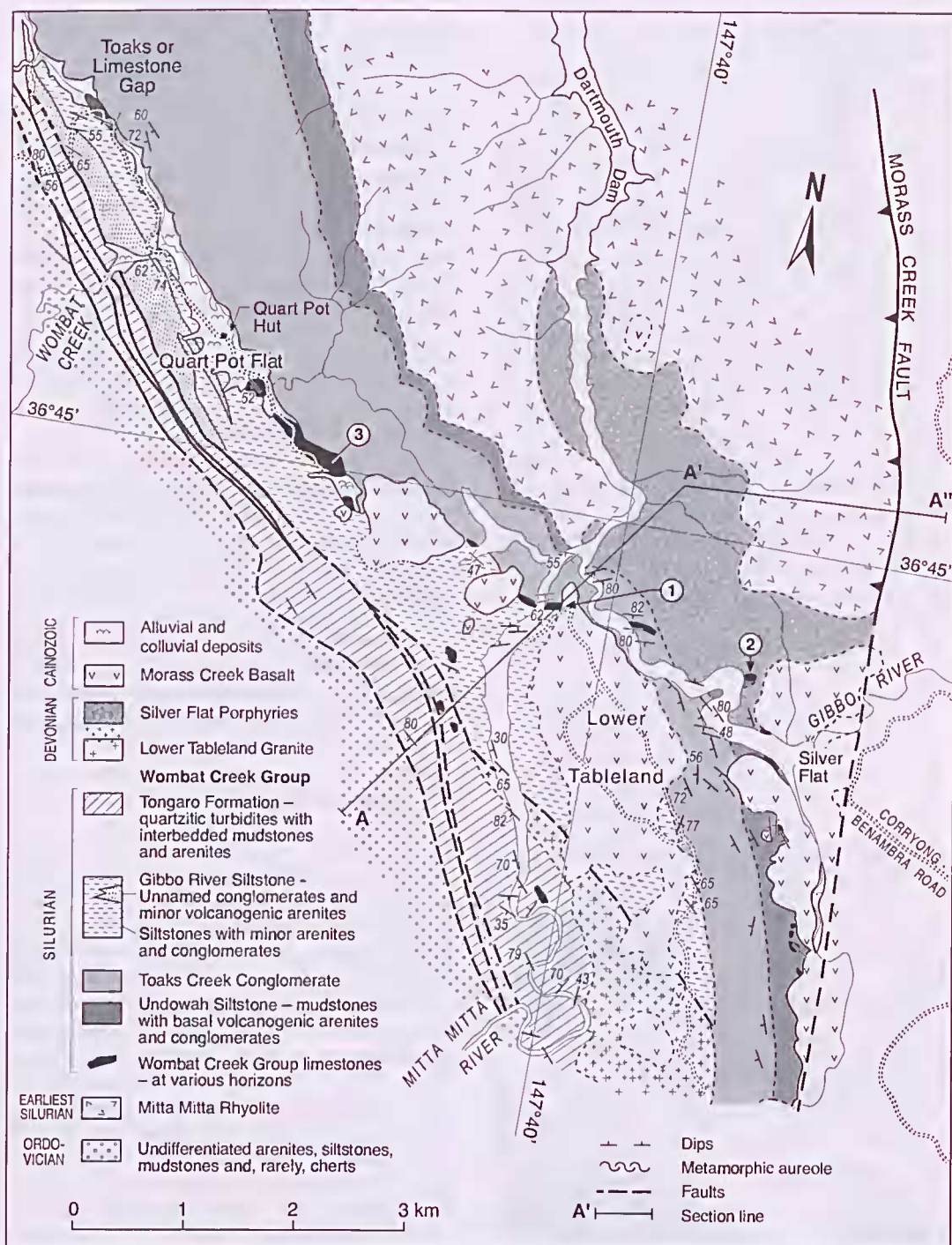


Fig. 2. Geology of Mitta Mitta River-Gibbo River-Wombat Creek region based on VandenBerg et al. (1998b). Localities 1, 2 and 3 refer to localities producing conodonts documented in his report — for details see appendix.

	SAMPLE	CAI	Distamodus staurognathoides	Ozarkodina eusthenensis			Ozarkodina cadiaensis			Ozarkodina eff. cadiaensis			Ozarkodina excavata excavata			Ozarkodina martinsoni eurliformis	Ozarkodina remsch. eosteinhomensis	Panderodus recurvatus	Panderodus ? n.sp.	Panderodus unicosolatus	Panderodus sp.	Pseudoboloidella silurica	Ozarkodina sp.	Sb	Totals										
				Pa	Pb	Sb	Sc	Pa	Pb	Sa	Sc	Pa	Pb	Sa	Sc	Pa	Pb	Sa	Pb	Pa	Pb	Sa	Sc	Pa	Pb	Sa	Sc	Sb							
1. "Lower Mitta ls."	0.0m	6		6	2	1	2	1												1					39	1									
	3.2m	6																		13	14				1	1									
	4.9m																								6	1									
	13.5m																			2	3					6									
	14.5m																			1						7									
	15.6m																			4	3					19									
	15.7m	6-6.5		2	1	2	1	1												4	5					23									
	17.1m																			11	5					3									
	18.3m																			1	1					1									
	19.3m																										14								
	20.5m	6		1	1															1	7					35									
	22.5m	6																		3	9	13				61									
	23.0m	6																		5	1	19	22			11									
	23.5m																			3	5					12									
	27.4m	6																		7	5					22									
2 Brammall Bluff	0.1m	4.5-5	2	1																1						8									
	5.7m																			1						7									
	11.2m																			2						2									
	16.7m																			1						2									
3. Quart Pot SE																										4									
4. Pyles deposit																										3									
5. "Wibenduck Ls."																										6									
Totals				4	3	10	3	2	18	13	3	3	1	2	1	1	1	5	2	1	2	7	1	1	7	8	1	1	1	85	102	1	1	1	292

Table 1. Distribution and colour alteration indices (CAI values) of conodonts from samples from measured sections through the "Lower Mitta" and Brammall Bluff ("Hair-pin") limestones, Gibbo R., and from spot samples from the Quart Pot and Pyle's limestones and the "Wibenduck Limestone". In the case of the Brammall Bluff section, the sampled section commenced 75 m upstream from the base of the carbonate-bearing sequence.

3. *Quart Pot limestone* (Loc. 3 — see Appendix)

Only four conodont elements were recovered from this unit. They are herein identified as elements of *Ozarkodina* aff. *cadiaensis*. It is therefore impossible to ascribe a reasonably accurate age for the deposition of this unit on available data. Given the stratigraphic context, however, a broad Early Silurian age is inferred.

4. *Pyle's limestone deposit* (loc. 4 — see Appendix)

Previous undocumented identifications of conodonts (Bischoff in Talent et al. 1975) implied the fauna is Přídolí or possibly Lochkovian in age (Simpson & Talent 1995: 82). This interpretation was based on a small number of form element taxa that could be interpreted as elements of *Ozarkodina remscheidensis* (Simpson & Talent 1995: 82). The identification in this study of a single Pa element as the subspecies *O. remscheidensis eosteinhornensis* restricts the age of the Pyle's deposit to the Silurian (latest Ludlow to mid Přídolí). This unit can be broadly correlated with the Native Dog limestone unit in the Limestone Creek region (Simpson & Talent 1995).

5. *"Wibenduck Limestone"* (Loc. 5 — see Appendix)

Conodonts reported but not documented from the "Winbenduck Limestone" (VandenBerg 1988: 131) were *Kockelella variabilis*, *K. ramuliformis*, *Ozarkodina confluens*, *O. excavata*, *Belodella anomalis*, and *Coryssognathus dubius* (recorded as *Pelckysgnathus dubius*). It has already been pointed out (Simpson 1995; Talent et al. 2003a) that *Kockelella ramuliformis* suggests a generalized Wenlock age, but may extend into the *Polygnathoides siluricus* Zone of the lower part of the upper Ludlow. *Kockelella variabilis* suggests *Ancoradella ploeckensis* and *Polygnathoides siluricus* zones, and *C. dubius* suggests the Ludlow. The fauna was thus thought to imply a generalized Ludlow age for the "Wibenduck Limestone" (Talent et al. 2003a). Lennart Jeppsson (pers. comm. 2003) has pointed out that on Gotland this association is restricted to a brief interval somewhere in the latest Gorstian–earliest Ludfordian.

It should be noted that none of the conodonts listed above have been examined by the authors. In this study only a small number of recognisable conodonts were recovered. These were elements of

Ozarkodina excavata excavata, a single Pa element of *Ozarkodina martinssoni auriformis*, and a Pb element of *Icriodus* sp.

O. martinssoni auriformis has been obtained from the Coral Gardens Formation of the Jack Group in the Broken River region (Simpson 2000, 2003). The taxon is interpreted as ranging from the Ludlow *siluricus* Zone to the latest Přídolí to Early Devonian *woschnidti* zone. Simpson (1998) reported the recovery of icriodontid elements from the top of the *siluricus* Zone from two localities in the Broken River region.

On available data, the "now lost" source of this allochthonous material correlates broadly with the autochthonous sequences spanning the upper parts of the upper Claire Creek limestone unit and interbedded carbonates and clastics directly overlying this unit in the Limestone Creek region (headwaters of the Indi River) (Simpson & Talent 1995). Because this fauna is from elasts of various lithologies, additional sampling could well produce minor chronological incongruities.

Conodont Colour Alteration Indices (CAI)

Determinations of CAI of the conodonts from this study (Table 1) have been made using a colour standard set of conodonts — of various shape, size and robustness — made available to us by Dr Anita Harris of the U.S. Geological Survey, thus obviating problems which might have arisen from inaccuracies in published colour illustrations (Epstein et al. 1977; Harris 1979 1981; Rejebian et al. 1987), or apparent differences in colour occasioned by relative robustness or delicacy of individual elements for which CAI values were being estimated.

Conodonts from four of the five localities investigated fall in the range of CAI 5.5–6 (Table 1), not very much above the overall average of 4.5–5.5 encountered over much of the Lachlan Foldbelt of eastern Australia for most Ordovician, Silurian and Devonian (early Givetian and older) platform sequences (Brime et al. 2003; Mawson & Talent unpub. data). Because the sequence at Bammall Bluff (loc. 2) had been reported to include skarn associated with felspar-quartz porphyry (VandenBerg et al. 1998a: 204), we anticipated that conodonts from this occurrence were likely to have high CAI values indicative of temperatures associated with skarns found adjacent to plutons (cf. Meinert 1992). Fluid inclusions, however, indicate prevailing

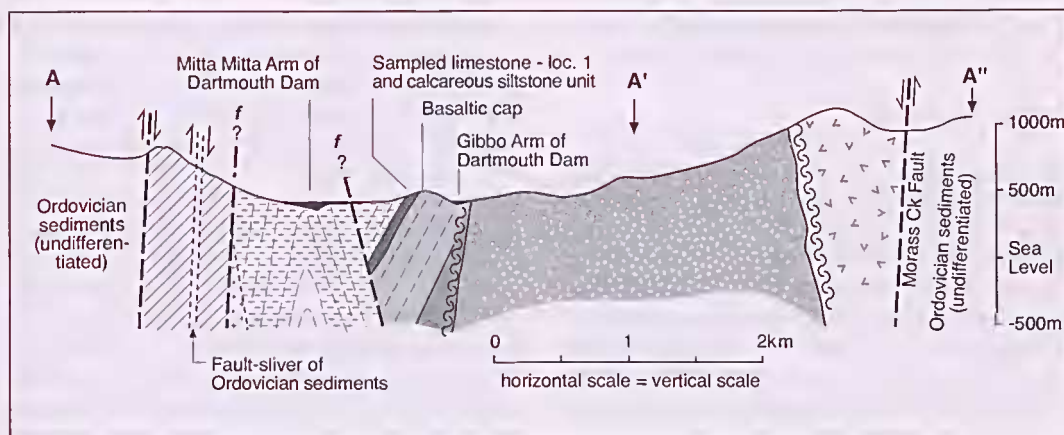


Fig. 3. Cross-section A-A'-A'' of Mitta Mitta River-Gibbo River-Wombat Creek region (for location see Fig. 2).

temperatures of formation of skarns in the range 300–700°C, but with occasional lower and much higher temperatures. The CAI values of conodonts from the Brammall Bluff sequence (loc. 2) are 4.5–5. This equates with about 250–350°C for 1–10 Ma of annealing (cf. Epstein et al. 1977; Harris 1979, 1981; Rejebian et al. 1987) — towards the lower end of temperatures for formation of skarns.

Even in hand specimens, the calcareous rocks of the tiny Pyle's limestone occurrence (Fig. 1; loc 4) can be seen to be recrystallized (Whitelaw, 1954); the metamorphism is presumed to have been connected with the nearby Brothers Syncline. The conodonts are transparent, indicating CAI values around 8, and much higher annealing temperatures than for the four other occurrences considered here. Three small limestone occurrences on the western flank of Morass Creek about 1.5–2 km above its junction with the Gibbo River are reported to have undergone skarn formation (Fig. 2; Birch et al. 1995; Vandenberg et al. 1998a: 205, 1998b); these were not sampled.

EASTERN VICTORIAN SILURIAN LIMESTONES: ALLOCHTHONOUS, AUTOCHTHONOUS, OR AN ENVIRONMENTAL MEDLEY?

Vandenberg et al. (1998a, 2000: p. 89) have argued for allochthonicity of the Silurian limestones of the Wombat Creek and Enano Groups of eastern Victoria. They have suggested, with some reservations due to generally poor exposures, that the numerous lime-

stone occurrences in these groups reflect carbonate accumulation on "lost" carbonate platforms (without terrigenous elastics) followed by displacement as olistoliths into deep-water contexts. Viewed this way, such limestones are taken to lack constraining age-significance for sequences in which they are now found. Llandovery and Wenlock ages indicated by conodont data from the Enano Group (notably Simpson & Talent 1995) and for the Wombat Creek Group (herein) are therefore to be discounted.

We accept that inferences as to autochthonicity or otherwise of most Cambrian-Pragian limestone occurrences in eastern Victoria should be approached with caution, especially in the absence of other palaeontological data — such as from graptolites or acritarchs — in the enclosing elastic sediments. Many such occurrences, long considered autochthonous, such as the Cambrian limestone-charged channel deposits and limestone olistoliths of the Dolodrook River (Talent et al. unpub. data), and the Early Devonian limestones of the Walhalla Syncline from Coopers Creek to Loyola (Mawson & Talent 1994) — the limestones of the Tyers-Boola area and minor parallel-bedded occurrences in the Wilson Creek Shale being the obvious exceptions — are indeed allochthonous, having been lithified prior to being dislodged and transported downslope. And we believe that at least some of the limestone occurrences in the Wombat Creek and Enano Groups are also allochthonous, but hesitate to assume all are allochthonous, and even more so that age-inferences from their faunas should be ignored — especially when shells were not broken or not even disarticulated before burial and lithification.

A. WOMBAT CREEK GRABEN (WOMBAT CREEK GROUP)

1. Mitta Mitta River

The elegant exposures now displayed as a result of erosion by waters of the Dartmouth Dam around the "Lower Mitta" limestone (VandenBerg et al. 1998a, 1998b) on the right and left flanks of the dam were a principal focus for the present investigation. Most attention was devoted to the right (eastern) flank of the dam (Loc. 1 in Appendix). Up-section, a gradual change from bedded to massively bedded limestone is followed by gradual change back through bedded limestones to interbedded, often crinoidal, limestones and mudstones. The overall upward decrease in calcareous content of the upper limestone-mudstone sequence is interpreted as reflecting a deepening event. The upper limestone-mudstone sequence seems also to reflect lack of lithification of some of the carbonate materials prior to reaching their final resting place, but this needs closer study. Retention of coherency of such a sequence during downslope transport seems unlikely, but we hesitate to reject the possibility that this limestone-elastic occurrence is olistolithic. We interpret the sequence as having probably accumulated *in situ*.

Upstream on the left bank of the Mitta Mitta River are intervals of conglomerate within the prevailing siltstone-arenite sequence with two small

patches with loose chunks of white limestone or marble sluiced out by the waters of the Dartmouth Dam; these limestones have failed to produce conodonts and appear to have been allochthonous. The superbly exposed limestone and calcareous mudstone body (Whitelaw 1954: fig. 2F; "Meanders 3" limestone lens of VandenBerg et al. 1998a) outcropping in a cliff on the right flank of the Mitta Mitta River about 3.6 km upstream from its junction with Wombat Creek was noted earlier. We view this occurrence, with prominent stylobrecciation, as probably autochthonous because of the wide range of lithologies, and the gradual transition from massive through bedded limestone to calcareous mudstones with limestone interbeds. In our view, it would have been difficult for such a sequence to retain stratigraphic coherence during major downslope displacement.

2. Gibbo River

We suspected that, because of association with conglomerates, the Gibbo River limestone occurrences mapped by Whitelaw (1954: figs. 3^A and 3^B) could be allochthonous. The Silver Flat limestone (Whitelaw 1954: fig. 3^B), outcropping poorly on both flanks of the Gibbo River, mostly rather marmorised and/or metamorphosed, and mainly covered by alluvials, could well be a large olistolith, 300 m or more in length, but possibly extending to the

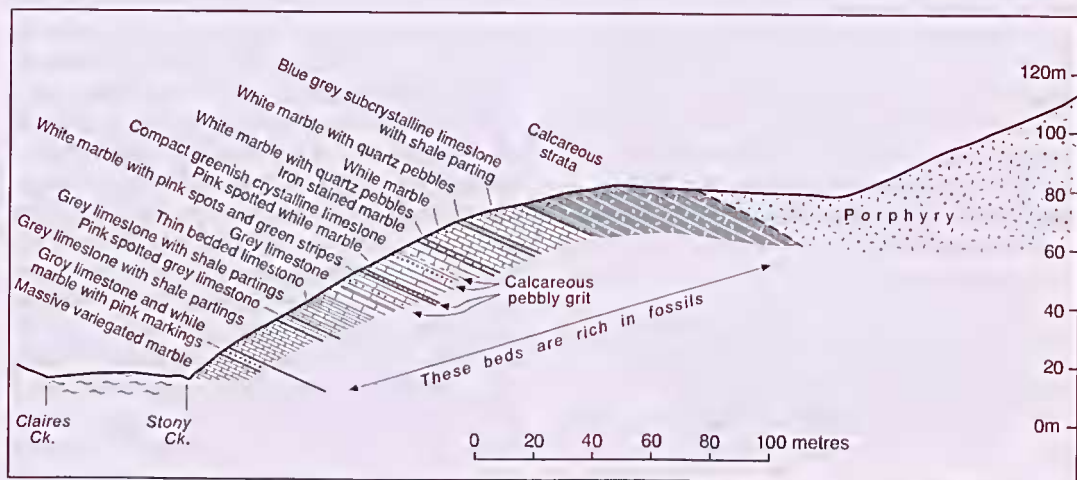


Fig. 4. H. S. Whitelaw's (1954: fig. 1) section, oriented northeast, crossing Claire and Stony Creeks about 80 m downstream from Charles Summer's northern marble quarry; lithologies in this sequence, now viewed as portion of the Cowombat Siltstone, are according to Whitelaw: the porphyry is Snowy River Volcanics (Early Devonian). This sequence, but with not the same alignment, together with overlying and underlying strata was sampled (185 samples) for conodonts by Simpson & Talent (1995: text-figs 2, 6, 7) along their sections SC (in part), SCA and SCV.

south-southeast beneath Cainozoic basalt and colluvial cover for > 1,000 m in length. Sampling of this occurrence failed to produce conodonts.

We agree with VandenBerg et al. (1998a, 1998b) that their "Lower Gibbo [limestone] olistolith" (Whitelaw 1954: fig. 3^A) is almost certainly an allochthonous block, but wave-action by the Dartmouth Dam has not revealed contacts between this massive limestone/marble body and the nearby conglomerate and fossiliferous shales.

The Brammall Bluff occurrence (= Whitelaw 1954, Fig. 3^B; = "Hairpin limestone olistolith and skarn" of VandenBerg et al. 1998a, 1998b) is complex, consisting of massive, yellow-buff-weathering carbonate for the first c. 75 m of outcrop, stratigraphically above which (upstream), commencing at 5607₉₆59314₆₃ on Benambra 1:50,000 topographic sheet 8424-3, the sequence becomes bedded with thin, irregular, rather bioclastic and nodular limestones (up to 2 cms thick) for about 37 m of outcrop. Eleven samples collected in this interval were acid-leached for conodonts. Farther upstream (for an additional c. 25 m) are yellow-buff-weathering carbonate blocks (to 5-m scale). These appear lithologically similar to the first 75 m of outcrop. They are not *in situ*, but appear to be olistoliths exhumed from the elastic sequence upslope, though none were noted within that sequence as presently exposed. We did not investigate the petrology of the yellow-buff-weathering carbonates, but were struck by the relatively good preservation of the fossils, mostly tabulate and rugose corals, occurring in isolation in matrix or in the thin beds of limestone within the elastic-cum-carbonate sequence. We accept that this tract has olistoliths (the yellow-buff-weathering carbonates), but suggest it also has beds of limestone apparently emplaced before lithification. Because of this we suggest that whatever palaeontologic information (mostly tabulate and rugose corals) can be derived from these limestones should not be dismissed in discussions of age of the associated strata.

Reconnaissance sampling of the "lower Gibbo" and Silver Flat occurrences failed to produce conodonts, but the sampled section through the Brammall Bluff occurrence (Loc. 2 — described above) produced sparse but useful faunas (Table 1). As indicated in the discussion of the conodont fauna above, it is possible to ascribe a relatively chronologically constrained time-interval to deposition of this sequence, and, as will be argued below, to infer broad synchronicity of Early Silurian carbonate dep-

osition in the Wombat Creek Graben and the Limestone Creek Half-graben to the east.

3. Wombat Creek and Toak's Gap

Our sampling of the Toak's Gap outcrops has failed to produce conodonts on several occasions but one occurrence, at the southeast end of the Quart Pot limestone tract (Loc. 3), possibly a continuation of the Toak's Gap occurrence, has produced a faunule consisting of elements herein interpreted as *Ozarkodina* aff. *cadiaensis*.

4. Pyle's limestone deposit

Despite poor exposures, the parallel bedding of the thin limestones we collected and acid-leached leads us to believe this occurrence is autochthonous. VandenBerg et al. (1998a) suggest that the Pyle's occurrence may be a tiny erosional remnant of limestone deposits that were much more extensive during Silurian times. They referred the Pyle's occurrence to the Undowah Mudstone, the oldest unit of the Wombat Creek Group. If this stratigraphic allocation is accepted, and the late-Ludlow–Prídolí age we attribute to this occurrence is also accepted, all or virtually all of the post-Undowah units of the Wombat Creek Group would be Devonian in age! We suggest, however, that this isolated occurrence is Gibbo River Siltstone, or possibly a younger unit of the Wombat Creek Group not represented in the main outcrop area of Wombat Creek Group (Fig. 2).

Our experience in investigating conodont faunas from allochthonous carbonate bodies — e.g., the Walhalla Synclitorium of eastern Victoria (Mawson & Talent 1994), the Broken River region of north-eastern Queensland (Sloan et al. 1995; Talent et al. 2003b) and the eastern flank of the Hill End Trough and the Tamworth Belt of New South Wales (Mawson et al. 1998; Talent & Mawson 1999) — indicates a high proportion of allochthonous carbonates in debris-flows have ages very little different from the age of the enclosing matrix, with a tendency to decrease in age up-sequence — as was demonstrated for the eastern flank of the Hill End Trough (Talent & Mawson 1999). Age-data from a single clast or olistolith may be problematic due to possibilities of platform collapse and downslope transport of olistoliths and smaller debris detached from deep within platform sequences. Dissection of carbonate plat-

forms upslope may, moreover, lead to increasing proportions of older clasts up-sequence, as was encountered with the carbonate clasts of the Thatch Creek section of the Perry Creek Formation of northeastern Queensland (Sloan et al. 1995). We believe, nevertheless, that "elast ages", judiciously evaluated, may be valuable where unequivocally autochthonous limestone horizons appear to be lacking.

5. Summary

We have found no compelling evidence for all limestone occurrences in the Wombat Creek Group being allochthonous or, alternatively, all autochthonous. We suggest that some of the Wombat Creek Group limestone occurrences are most likely allochthonous, but others appear to be autochthonous. The Brammall Bluff occurrence (Loc. 2) we suggest is substantially allochthonous, but portions of the sequence — because of thin, parallel-bedded limestones, interpreted as having been lithified subsequent to deposition — are believed to be largely if not entirely autochthonous, and conodonts from them (Table 1) constrain the age of the strata with which they are interleaved. The majority of other limestone occurrences in the Wombat Creek Group — with outcrops not allowing resolution of relationships to nearby clastics — are best categorised as suspect.

B. LIMESTONE CREEK HALF-GRABEN (ENANO GROUP)

Prior to our sampling of various sequences in the northern part of the Limestone Creek Half-graben, all carbonates in the region had been accorded a generalised Late Silurian age (e.g., VandenBerg 1988; Walley et al. 1990). Our sampling of numerous carbonate intervals in this region revealed a much broader spectrum of ages: from early Llandovery to Přídolí *eosteinhornensis* Zone (Simpson & Talent 1995; Talent et al. 2003a). Subsequently, VandenBerg et al. (1998a, 2000) suggested that the limestone occurrences in the Enano Group, cropping out in the headwaters of the Indi, Buchan and Tambo Rivers, may be allochthonous and that palaeontologic data derived from them by us (Simpson & Talent 1995) may not be compelling for dating associated strata. As this suggestion has

implications for the tectonic scenario presented by VandenBerg and his colleagues, we dwell a little on the question of allochthonicity *versus* autochthonicity of the carbonate units for which we have previously presented conodont data.

Our sparse conodont data from the McCarty's limestone lens (Simpson & Talent 1995: text-fig 3A) are biostratigraphically consistent with it being a stratigraphically coherent body. It has produced the oldest conodont assemblages (early Llandovery, Rhuddanian) so far obtained from the region. Whether or not it is a fault-bounded body, autochthonous, or a large olistolith cannot be determined because of the absence of exposures displaying relationships of the limestone to nearby clastics.

Because of its well-bedded character, we are disinclined to accept an allochthonous interpretation for the highly fossiliferous Lobelia limestone lens (Simpson & Talent 1995: text-fig. 4) of the Reedy Creek area; it has produced conodonts indicative of the late Llandovery–earliest Wenlock *celloni-amorphognathoides* interval. The Farquhar limestone lens, about 1.5 km along strike from the Lobelia lens, is conspicuously more massive and more recrystallized than the latter. It could be allochthonous but, because it is the same age as the Lobelia lens and located more or less on strike with the latter, we are not inclined towards an allochthonous interpretation for this limestone lens, but such is indeed possible. Unequivocal answers might be possible from a minimum of trenching across strike of the boundaries of these two occurrences.

The Claire Creek–Stoney Creek outcrop-tract, in the central parts of the region, consists of two main limestone units separated by a pelitic sequence with subordinate carbonates, followed by a sequence with generally decreasing ratio of carbonate to clastics. In an earlier phase of nomenclatorial zeal (Talent et al. 1975), the entire package was referred to — in line with recommendations of the then code of stratigraphic nomenclature, to emphasize prominent or dominant lithologies — as the Claire Creek Limestone Member. Though this section was heavily sampled (367 samples) over a distance of 1.4 km (Simpson & Talent 1995, text-figs. 2, 6, 7, tables 2–5), it displays no inconsistencies in conodont biostratigraphy. VandenBerg (unpub. ms.) however challenged this, pointing out an overlap of two index taxa (*A. ploeckensis* and *O. sagitta*), previously thought to be chronologically separate, in the lower part of the upper Claire Creek limestone unit. This we regard as trivial, with no bearing on the regional

synthesis previously presented (Simpson & Talent 1995).

Despite metamorphism to lower greenschist facies and poor yields of conodonts, particularly for the lower limestone unit, data are sufficient to indicate deposition through a large slice of Silurian time (cf. Table 2; Simpson & Talent 1995). Near basal samples of the lower limestone unit have produced a tentatively identified taxon *Ozarkodina aldridgei* that suggests an earliest possible age of middle Acronian (Simpson & Talent 1995). The higher intervals of the lower limestone unit have produced poor faunas typical of the late Llandovery to early Wenlock *celloni* and *amorphognathoides* zones. Equivocal fragmentary specimens from near the top of the lower unit suggest that, like the McCarty's limestone lens, the lower limestone unit may extend into the "post-*amorphognathoides*" interval of the Wenlock. The lower intervals of the "upper limestone unit" (cf. fig. 5) are typified by taxa indicative of a broad Wenlock age. Higher in the unit, there is an overlap of the zonal index species of the typically European Wenlock *sagitta* Zone with the first appearance of zonal index species of the cosmopolitan Ludlow *ploeckensis* Zone. We regard this apparent biostratigraphic disparity as being inconsequential.

The identification of the single specimen of *O. sagitta* has been questioned by Corradini & Serpagli (1999). One of us (AS) has subsequently had the opportunity to compare the specimen with topotype material of *O. sagitta* from Europe and must agree that the original identification is equivocal. More sampling is required to resolve the issue. Should the interpretation of Corradini & Serpagli (1999) prove correct, this implies resumption of carbonate sedimentation in the Limestone Creek region in the early Ludlow rather than the late Wenlock. It would also remove any scintilla of biostratigraphic dissonance that could possibly be construed as supporting evidence for an allochthonous origin.

Faunas above this level, high in the "upper limestone unit", are typically Ludlow in aspect (Simpson & Talent 1995). Constrained by data from the overlying and underlying limestone units, the intervening pelitic sequence is therefore inferred to be broadly Wenlock in age. Intermittent carbonates in the predominantly clastic sequence overlying the "upper limestone" interval also yield broadly Ludlow faunas. Despite the lack of index species, this latter sequence is thought to extend well into the later Ludlow.

In our earlier sampling (Simpson & Talent 1995) we gave special attention to the Claire Creek–Stoney

Creek sequence because of the exceptional length of the sequence, and the lengthy intervals of excellent exposure. The diverse lithologies are indicated in a cross-section by Whitclaw (1954, section A, redrawn as Fig. 4 herein). From our experience, such lithologically diverse and generally thin-bedded sequences characterized by a broad spectrum of lithologies and contrasting competence — with a significant proportion of mudrocks — would have been prone to disintegration during major downslope movement. Moreover, brachiopods from the various lithologies in this section, admittedly not abundant, are overwhelmingly articulated. Though conceivable, this is not what would be anticipated if the unlithified sediments had undergone substantial downslope transport as olistostromes. We are therefore inclined to view this, the most important Cowombat Siltstone sequence, as autochthonous. We accordingly accept the conodont data obtained from it as indicating true ages for the sequence as a whole — i.e. from mid-Acronian (mid-Llandovery) to the late Gorstian (Early Ludlow) *ploeckensis* Zone, probably extending into the Ludfordian (late Ludlow) — and not depositional ages: somewhere on an adjacent platform prior to being dislodged and deposited in basinal contexts.

The largest tract of Silurian limestone in the valley of Limestone Creek, extending for approximately 2 km from Jim Spean Creek (Kimberley Hut area) through the Pendergast's Cave and Sheehan's Bluff areas (Whitclaw 1954, fig. 1^c), may be interpreted as a single autochthonous or allochthonous slab or, because of a substantial tract of alluvials and older terrace gravels about Painter Creek, interpreted as possibly two large olistoliths. We incline to the former interpretation but, because of poor exposures of the nearby clastics and absence of exposures displaying contacts between the limestones and clastics, the nature of this body (or bodies) cannot be compellingly demonstrated. The age of this body (or bodies) is uncertain. No conodonts were obtained from a section sampled across strike through Sheehan's Bluff, but a few poorly preserved and chronologically inconsequential *Panderodus* obtained from samples from a section approximately 600 m along strike north of Sheehan's Bluff give hope that additional sampling may eventually provide chronologically useful data.

Among limestone occurrences only cursorily examined and sampled by us are some which have parallel-bedded and occasionally bioelastic limestones, e.g. the Philip's Bluff and Little Stoney

Creek occurrences (Whitelaw 1954: fig. 1^B); these we believe are probably autochthonous. Like the Sheehan's Bluff section (see above), these have produced only a few poorly preserved *Panderodus*. Others, such as those on the western flank of Limestone Creek in the northern part of Whitelaw's fig 1^C are parallel-bedded and interbedded with clastics; these limestones appear to be autochthonous but could be alloclastic. We suspect that the body through which we sampled our section LC (Simpson & Talent 1995: upper part of text-fig. 2; table 1) with, inter alia *Ozarkodina australensis*, may be allochthonous, but there is an absence of exposures displaying relationships of the limestone to nearby clastics.

The occurrences in the valley of Annabella Creek and adjacent parts of Limestone Creek (Whitelaw 1954, fig. 1^A) appear to be allochthonous. These and limestones intimately associated with acid and intermediate volcanics, volcanic breccias and greywackes farther south in the vicinity of the Wilga and Currawong prospects (Allen 1991) appear also to be allochthonous, but these occurrences need to be cautiously probed for relationships in the field and from the large corpus of bore cores available at the Benambra Mine. At least one limestone occurrence in this area, outcropping on and adjacent to the Teapot Track Creek in the vicinity of 837,080_n, consists of limestone clasts and is therefore unequivocally allochthonous. This occurrence failed to produce conodonts.

An isolated limestone lens among richly fossiliferous calcareous mudstones at Cowombat Plain has yielded late Ludlow *crispa* Zone conodonts (Simpson et al. 1993). The interval of fine clastics above this lens, exposed in Native Trout Creek, is therefore most probably Přídolí in age. Conodonts from limestones associated with clastics at Native Dog Plain are generalised Late Silurian associations, but high in the sequence are faunas typical of the Přídolí *eosteinhornensis* Zone. The range-base of the name-giving taxon predates the Ludlow–Přídolí boundary in many parts of the world (Aldridge & Schönlaub 1989). However that may be, the occurrence at Native Dog Plain seems to be the youngest preserved

horizon in the tracts of Silurian rocks outcropping in the headwaters of the Indi, Buchan and Tambo Rivers. These sequences extend the age-spectrum for the Cowombat Formation to higher horizons than those encountered in the Stoney Creek–Claire Creek sequence. The massive limestone in the lower part of the Native Dog sequence aside, these sequences are shaley with minor limestones, not the sort of sequences we would anticipate likely to retain coherence during grand-scale downslope movement.

In summary, though we earlier noted that the Enano Group included allochthonous limestones (Conaghan et al. 1976: 529, as Cowombat Group), we did not view all limestone occurrences in that unit, nor, for instance at Tyers River and Tamworth areas cited in the same paragraph, to be exclusively allochthonous, though, regrettably, this was not unequivocally asserted. Our subsequent sampling of the Enano Group and Wombat Creek Group have produced no compelling evidence for all limestone occurrences in the two regions to be exclusively either allochthonous or autochthonous. We accept that some of the limestone occurrences in both regions are allochthonous, but others (possibly a minority) appear to be autochthonous and therefore of value in dating the enclosing sediments. Others, where outcrops do not allow resolution of relationships to nearby clastics, are best categorised as suspect until additional data become available.

We draw attention to the profound influence of faulting in preservation of the Silurian sequences in the Wombat Creek Graben and Limestone Creek Half-graben, and see no reason why these fault boundaries have any necessary relationship to the former boundaries of the sedimentary "basin" (or "basins") in which these sedimentary packages accumulated. Similarities, admittedly very broad, in depositional sequence and in chronologic alignments between the two regions suggest that the sequences in the two regions may be viewed as possibly now-disjunct portions of a formerly continuous sedimentary pile. In other words, their preservation in now separate tracts may be an artefact of post-depositional tectonics.

Table 2. Silurian correlations advocated on the basis of conodont data presented here and by Simpson et al. (1993) and Simpson & Talent (1995, 1996), compared with correlations suggested by VandenBerg et al. (1984–1999, principally 1998a). Scale on the left is based on Zhang & Barnes (2002) for the Llandovery, Jeppsson (1997e) and Calner & Jeppsson (2003) for the Wenlock, and Jeppsson (in Eriksson 2001) for the Ludlow and Přídolí. Abbreviations for generic names in the conodont zones are as follows: *An.* = *Ancoradella*, *Ancy.* = *Ancyrodelloides*, *Ct.* = *Ctenognathodus*, *I.* = *Icriodus*, *K.* = *Kockella*, *Oz.* = *Ozarkodina*, *Ou.* = *Oulodus*, *Ped.* = *Pedavis*, *Pol.* = *Polygnathoides*, *Ps.* = *Pseudoneotodus*, *Pt.* = *Pterospathodus*.

C. SARDINE CREEK ("WIBENDUCK LIMESTONE")

A tract of Silurian rocks about 32 km north-north-east of Orbest first noted by Stirling (1888a) and formerly referred to as the Sardine Beds (Talent et al. 1975; Taylor 1984), was regarded as consisting of two units, the Sardine Conglomerate (a submarine fan deposit) overlain by Wibenduck Limestone (VandenBerg 1988; VandenBerg et al. 1992). There are no exposures of the contacts between the Wibenduck Limestone and adjacent tracts of conglomeratic Sardine Conglomerate *sensu stricto* nor of the former with the Warbiseo Shale (Ordovician), though it is probable that the latter is a fault boundary. We interpret the "Wibenduck Limestone" to consist of elasts of various carbonate and calcareous lithologies, lithified before cannibalisation and incorporation into the fan deposit. We thus regard it as a limestone-charged debris flow at the top of the spectacular Sardine Conglomerate fan deposit (Talent et al. 2003a) rather than as a discrete formation.

Conodonts from the "Wibenduck Limestone", reported (VandenBerg 1988: 131) but not documented previously, were reviewed by Talent et al. (2003a). They concluded that the fauna is consistent with a generalized Ludlow age and opined that the fan may be interpreted as a reflection of Late Silurian synorogenic sedimentation. Conodonts recovered in this study generally indicate a mid to late Ludlow age (probably latest Gorstian–earliest Ludfordian) consistent with the cannibalisation and re-deposition scenario suggested here.

The conodonts obtained from acid-leaching limestone float and from samples from a tiny quarry beside the Scanlon Creek Track (type locality of the "Wibenduck Limestone", VandenBerg et al. 1992: 27; see Appendix, loc. 5) have a high breakage ratio, consistent with appreciable transport of much of the fauna prior to lithification, somewhere upslope — from wherever the elasts may have been derived. The age indicated by the "Wibenduck Limestone" could thus be older, even appreciably older, than the age of accumulation of the Sardine Conglomerate fan deposit. We suggest the latter to be an analogue of the Sharpeningstone Conglomerate of the Yass district of southern New South Wales, a unit closely connected chronologically with the onset of the Bowring Orogeny — cf. conodont data for the Elmside Formation and Sharpeningstone Conglomerate in Link & Druce (1972).

TECTONIC IMPLICATIONS

A "package" of events — deformation, regional metamorphism, and plutonism — during latest Ordovician–Early or mid-Silurian times (the traditional view), or Late Silurian in eastern Victoria (VandenBerg et al., e.g. 1998a, 2000) — has long been assumed to have impacted more dramatically on the geological evolution of eastern Australia than any other "package" of events during the last 500 million years. This has long been referred to as the Benambran Orogeny (e.g. Browne 1947; Packham 1969; Scheibner 1998; Reed 2001). During the last decade, an alternative view has developed, that Silurian and Devonian orogenic events, including the "Benambran" events, were not clustered into discrete time-slices — see debate: Gray & Foster 1997, 1998, 1999; Gray et al. 1997; Foster et al. 1999, 2000; Foster & Gray 2000; VandenBerg 1999; VandenBerg et al. 2000; Collins & Hobbs 2001). That there can be such divergent opinions underlines the poor knowledge of most major events (or sub-events) during that interval, especially as regards time-control on the sedimentary sequences reflecting events "set in train" by deformation.

In a recent survey of stratigraphic alignments for the Silurian of Australia, Talent et al. (2003a) re-affirmed that there was indeed a hiatus equating with much or all of early and middle Llandovery time in eastern Australia and, in most cases, a striking angular unconformity associated with a profound contrast in tectonic style between juxtaposed units. In most areas, such as in the vicinity of Canberra, Quidong, Bungonia and the Broken River region of northeast Queensland, the dramatic contrast in deformation between the juxtaposed units implies greater tectonic activity than occurred during the remainder of Silurian and Devonian time. However, during a recent debate on diastrophism in the Lachlan Fold Belt of south-eastern Australia (see references above), contrasting scenarios were presented for the entire Late Ordovician–Devonian interval (including the "Benambran" time-slice): west-east continuous (non-episodic) diastrophism connected with essentially continuous subduction-induced deformation ("Lachlan Orogeny") *versus* discrete/episodic events. Disagreement included the significance regarding spatial and temporal variation in deformation that might be inferred from Ar–Ar dates on white micas — argued to reflect migration of the cleavage front in the "deforming sedimentary pile". The Ar–Ar database is, however, sparse and has been obtained mostly from the western part of the Lachlan Fold Belt. The eastern part of the Lachlan

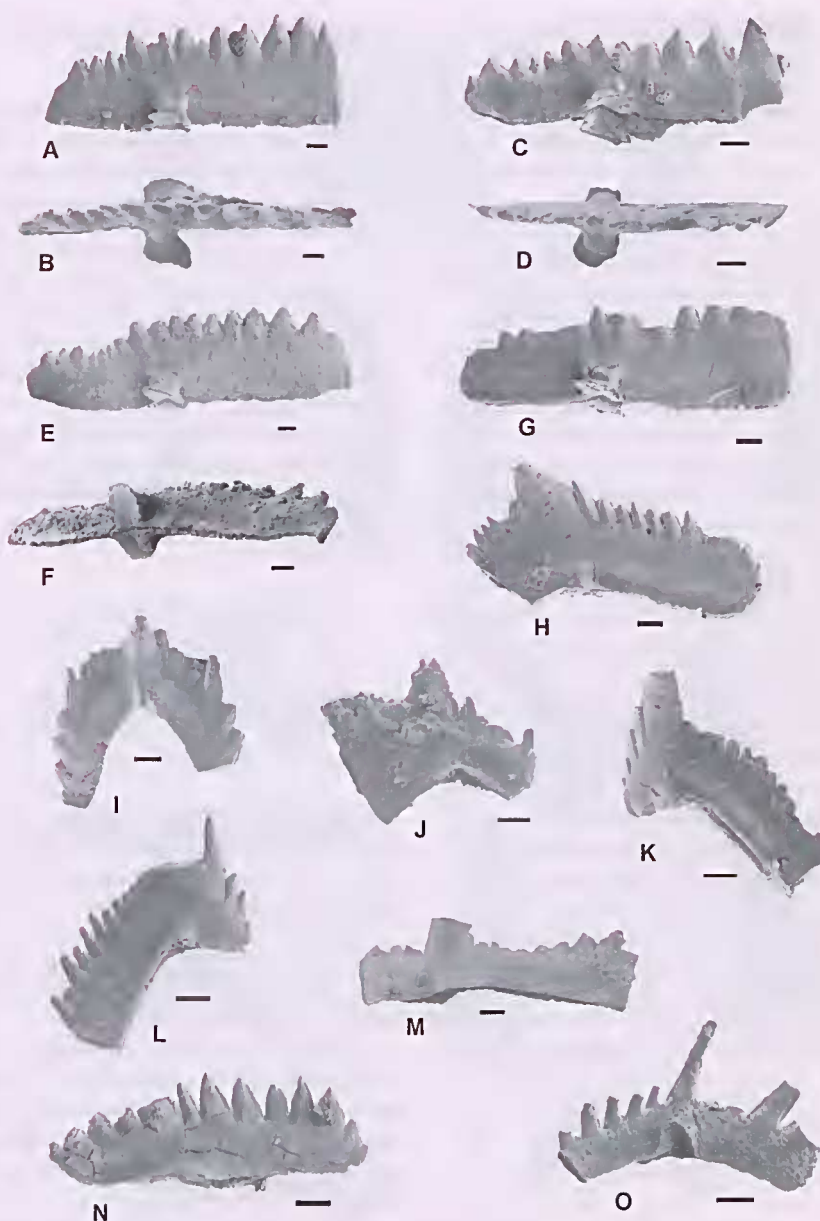


Fig. 5. Early Silurian (Llandovery) conodonts from stratigraphic section through the "Lower Mitta" limestone body on the right (east) flank of the Mitta Mitta River, eastern Victoria. The location is indicated on Fig. 2 and determinations are presented in Table 1. All specimens are housed in the Australian Museum, Sydney, with prefix AMF.

A-I, *Ozarkodina cadiaensis* Bischoff, 1986. A, B. Pa element, 3.2m, inner lateral and upper views respectively of AMF 125116. C, D. Pa element, inner lateral and upper views respectively of AMF 125117, 27.4m. E, F. Pa element, inner lateral and lower views respectively of AMF 125118, 15.7m. G. Pa element, outer lateral view of AMF 125119, 22.5m. H. Pb element (incomplete), lateral view of AMF 125120, 22.5m. I. Sa element, inner lateral view of AMF 125121, 27.4m. J. Sb element, inner lateral view of AMF 125122, 15.6m. K. M element, inner lateral view of AMF 125123, 15.6m. L. M element, inner lateral view of AMF 125124, 15.6m. M-O. *Ozarkodina australensis* Bischoff, 1986. M. Se element of AMF 125125, 20.5m. N. Pa element, inner lateral view of AMF 125126, 20.5m. O. Sb element of AMF 125127, 23.5m.

Fold Belt, including the areas that form the foci of the present report, has large tracts that appear to be less amenable to regional Ar–Ar dating of metamorphic micas, so palaeontologic data in conjunction with sedimentary and tectonic data retain importance in the discussion for eastern Victoria and south-eastern New South Wales.

We suggest that whatever tectonic scenario is put forward should not ignore the evidence of well-dated major unconformities reflecting intense deformation, or biostratigraphic data (unless derived from demonstrably allochthonous material). If as we suggest, some of the Enano and Wombat Group carbonate intervals are autochthonous and pre-Ludlow, then the tectonic scenario should be made to accommodate these data. Our view is the traditional view: that a substantial “package” of events — deformation, regional metamorphism, and plutonism — indeed took place during the Llandovery, especially early- and mid-Llandovery times, but an integrated story of what happened (tectonic, igneous and sedimentary) during the Silurian has still to be spelled out with good chronologic underpinning. The picture is more complex than may at first appear. Some of the sequences, long asserted to be Late Silurian (e.g. by Walley et al. 1990), in fact fall within the latest Ordovician–Llandovery/earliest Wenlock interval. We are aware that linkages between deformation, uplift, erosion and derived sedimentation may be complex, with the possibility that unconformity-bound sedimentary packages resulting from erosion and sedimentation “set in motion” by a specific cycle of deformation could post-date the onset of the deformation by as much as “several million years” (Foster et al. 2000: 816) — and be diachronous. Clearly, there is a long way to go before the Benambran events have been adequately deciphered and compelling linkages established.

TAXONOMIC NOTES

***Ozarkodina australensis* Bischoff, 1986**
Fig. 5, M–O, Fig. 6, H, K, L, O, P, Fig. 7, O.

Ozarkodina australensis Bischoff 1986: 126, pl. 22, figs 1–21. — Simpson & Talent 1995: pl. 7, figs 2–22.

Ozarkodina excavata eosilurica Bischoff 1986: 137, pl. 25, figs 10–34.

Ozarkodina sp. C Armstrong 1990: 96, pl. 14, figs 17–18, 20.

Remarks. Bischoff (1986) obtained several *Ozarkodina* specimens from mid-western New South Wales from earliest and pre-Wenlock strata, separated these into different taxa, and suggested an evolutionary relationship with the younger *Ozarkodina excavata excavata*. Simpson & Talent (1995: 140) placed two of these, *O. australensis* and *O. excavata eosilurica*, in synonymy. Closely similar Pa elements with short blades and straight to slightly concave basal margins were recovered from the Mitta Mitta Formation. Whilst these elements have a morphology superficially resembling the highly variable *O. excavata excavata*, numbers are too low to shed any further light on evolutionary relationships, so the taxonomy of Simpson & Talent (1995) is retained.

***Ozarkodina cadiaensis* Bischoff, 1986**
Fig. 5, A–I, Fig. 7, H, L, M.

Ozarkodina cadiaensis Bischoff 1986: 132, pl. 24, figs 11–27, 30. — Simpson & Talent 1995: 142, pl. 7, figs 23–25.

Remarks. This taxon has a distinctive Pa element characterised by the V-shaped separation between the cusp and adjacent denticle, decline in denticle height from anterior to posterior, and the small rounded basal cavity with pinched basal margins. All elements of *Ozarkodina cadiaensis* are characterised by small closely packed denticulation and restricted basal cavities.

Bischoff (1986: 133–134) provided descriptions of the Pa, Pb, and M elements. In the symmetry transition series he recovered only the Se element. In this study we recovered all of the above elements and identified distinctive Sa and Sb elements. Brief descriptions are given below.

Sa element: Alate element with minute basal cavity, high lateral processes with concave lower margins separated by an acute angle. Proximal denticles are erect, distal denticles inclined outwards giving an overall “fan-like” appearance.

Sb element: Digyrate element with small rounded basal cavity, one high lateral process and one low lateral process both with small closely packed denticulation abutting prominent cusp.

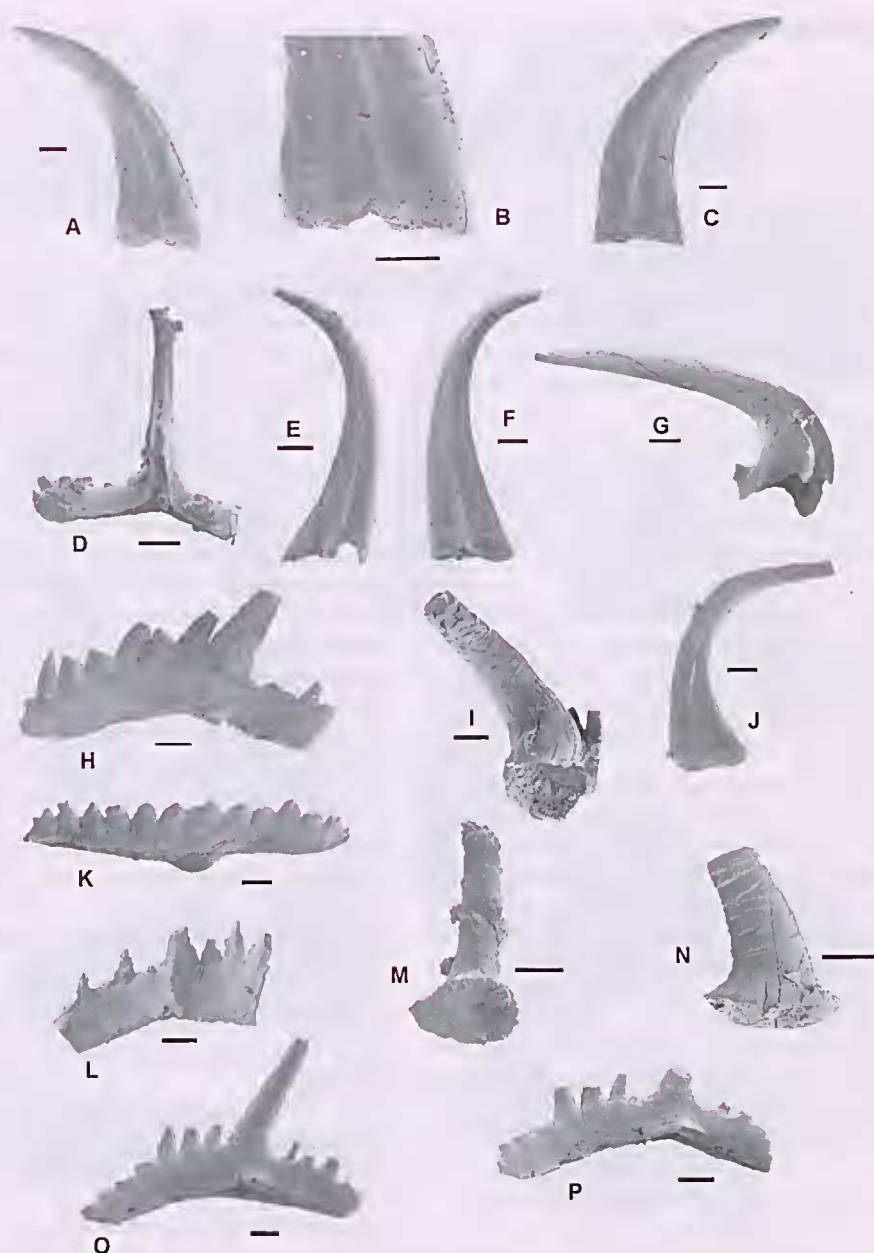


Fig. 6. Early Silurian (Llandovery) conodonts from stratigraphic section through the "Lower Mitta" limestone body on the right (cast) flank of the Mitta Mitta River, eastern Victoria.

A-C *Panderodus* sp. A, B lateral view and enlargement respectively of AMF 125128, 22.5m. C. lateral view of AMF 125129, 22.5m. D. *Ozarkodina excavata excavata* (Branson & Mehl 1933) Sa element, inner lateral view of AMF 125130, 19.3m. E, F. *Panderodus unicostatus* (Branson & Mehl 1933) lateral views of AMF 125131, 3.2m and of AMF 125132, 19.3 m respectively. G, I, M, N. *Distomodus staurognaethoides* (Walliser 1964). G. Sb element, lateral view of AMF 125133, 22.5m. I. Sc element (fragmentary), posterior view of AMF 125134, 19.3m. M-N Undifferentiated cones, 3.2m, AMF 125135 and AMF 125136, respectively. H, K, L, O, P. *Ozarkodina australensis* Bischoff, 1986. H. Pb element, inner lateral view of AMF 125137, 18.3m. K. Pa element, upper view of AMF 125138, 3.2m. L. Sb element, inner lateral view of AMF 125139. O, P. Pb elements, inner lateral views of AMF 125140 and of AMF 125141, respectively, 3.2m. J. *Panderodus recurvatus* (Rhodes 1953) lateral view of AMF 125142, 15.6m.

Ozarkodina aff. *cadiaensis* Bisehoff, 1986

Fig. 7, A–E.

Description. Pa element: Carminate element with a short posterior process and long anterior process. Lower margins of processes are straight, meeting at less than 180 degrees, giving a coneave appearance to the lower margin. Small rounded basal cavity located in posterior half of element beneath, and slightly anterior to prominent eusp. Posterior process is low with two or three small proximal denticles and one larger distal denticle. Anterior process relatively high with seven or eight large denticles of generally equivalent size.

?Pb element: Angulate element with prominent cusp and large denticles (element incomplete).

?Sa element: Alate element with prominent eusp and thick processes with narrow ledges beneath subdued denticulation (element incomplete).

Remarks. Three different element types (two of which are represented only by fragmentary specimens) were recovered from the same sample from the southeastern end of the Quart Pot limestone. Morphological similarities enable them to be grouped tentatively in the one taxon.

The Pa element strongly resembles *Ozarkodina cadiaensis*, in particular with respect to the size and structure of the basal cavity. The main differences are the subdued denticulation on the posterior process, the more prominent eusp and the less obvious development of a V-shaped separation between denticles above the basal cavity. More specimens are required to establish whether this form is aberrant but within the range of intraspecific variation for *O. cadiaensis*, or whether it represents a separate taxon. Without intermediate morphologies it is not possible to imply this form is related in some way to *O. cadiaensis*; it is therefore left in open nomenclature.

Ozarkodina excavata excavata

(Branson & Mchl, 1933)

Fig. 6, D, Fig. 8, C, D, F.

For synonymy see Simpson & Talent (1995) and add the following:

Aspelundia fluegeli (Walliser): Pereival 1998: Fig. 3.6.

Ozarkodina excavata (Branson & Mchl): Miller 1995: pl. 1, fig. 8.

***Ozarkodina excavata excavata* (Branson & Mchl) –**

Barca et al 1992: pl. 10, figs 3–5; – Sloan et al. 1995: pl. 12, figs 15, 18; – Simpson & Talent 1995: 147–153, pl. 8, figs 16–25, pl. 9, figs 1–24; – Colquhoun 1995: pl. 1, fig. 16; – Furey-Greig 1995: pl. 1, figs 12–14; – Carcy & Bolger 1995: 79–81, Fig. 3G–H; – Serpagli et al. 1998: pl. 1.2.1, figs 4–5; pl. 1.2.2, fig. 1; – Corradini et al. 1998: pl. 1.3.1, fig. 1; – Ferretti et al. 1998: pl. 2.2.1, fig. 1; – Pereival 1998: Fig. 4.2; – Talent & Mawson 1999: pl. 5, figs 1, 3–4; pl. 5, figs 1–4; pl. 6, figs 19–22; pl. 9, figs 8–9; – Cockle 1999: 120, pl. 3, figs 1–14; – Talent et al. 2003a: pl. 2, figs R–S, pl. 3, fig. S, pl. 4, fig. K.

Remarks. This is one of the most numerically abundant, highly variable and widely recognised conodont taxa recovered from Silurian strata. Simpson & Talent (1995: 147–153) discuss this subspecies and its differentiation from the older and probably closely related *Ozarkodina australensis*. The fauna from this study add no new insights to the question of the relationship between *O. excavata excavata* and *O. australensis*. It would be unwise to preclude the possibility that better faunas from more continuous sequences may indicate a closer phylogenetic relationship than inferred herein. Until this time the taxonomy and interpretations of Simpson & Talent (1995) are retained.

Ozarkodina martinsoni auriformis

Simpson, 2003

Fig. 8, A–B.

For synonymy see Simpson (2003) and add the following:

Ozarkodina martinsoni auriformis Simpson 2003 – Talent et al. 2003a: pl. 2, fig. T.

Remarks. The distinctive Pa element of this taxon is readily separated from other Pa elements in this study such as *Ozarkodina cadiaensis* on the following morphological criteria. *O. martinsoni auriformis* has a distinctive two-level height of denticle development, and denticle-size is relatively even on both the anterior and posterior processes. *O. cadiaensis* has an undulose development of denticles in lateral outline. The basal cavities of *O. martinsoni auriformis* and *O. cadiaensis* are similar in having pinched margins close to the blade. The basal cavity

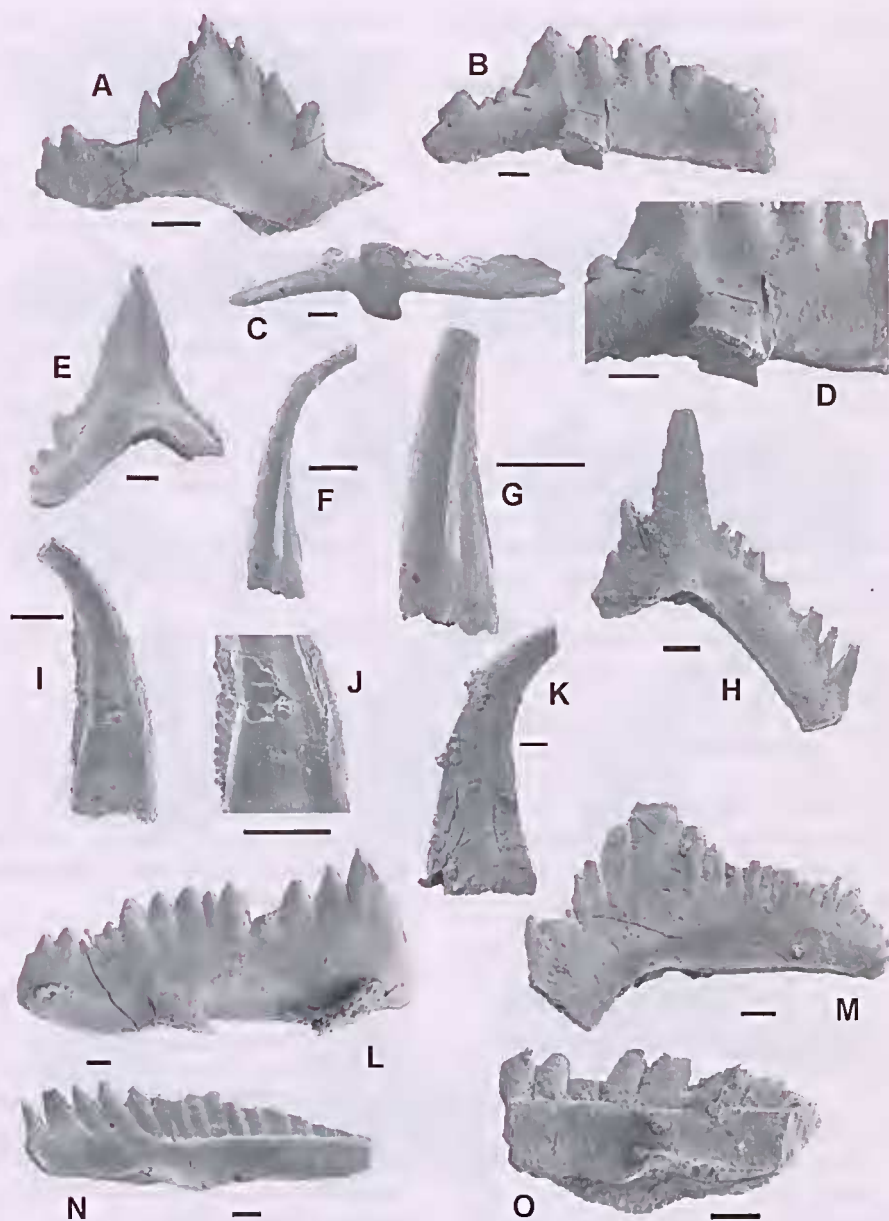


Fig. 7. Early Silurian (Llandovery) conodonts from stratigraphic section at Brammall Bluff on the Gibbo River (locality 2; = 'Hairpin limestone' of VandenBerg et al. 1998a), and from a spot sample at locality 3, at SE end of Quart Pot limestone tract. Locations are indicated on Fig. 2.

A-E. *Ozarkodina* cf. *cadiaensis* Bischoff 1986. A. Pb element, lateral view of AMF 125143, Loc. 3. B-D. Pa element, lateral view, lower view and enlargement of basal cavity respectively of AMF 125144, Loc. 3. E. Sa element, lateral view of AMF 125145, loc. 3. F, G. *Panderodus unicostatus* (Branson & Mehl 1933) lateral view and enlargement of AMF 125146, Loc. 2, 0.1m. H. *Ozarkodina cadiaensis* Bischoff 1986 M element, inner lateral view of AMF 125147, Loc. 2, 0.1m. I, J. *Pseudobelodella silurica* Armstrong 1990 aq element lateral view and enlargement respectively of AMF 125148, Loc. 2, 5.7m. K. *Panderodus* sp., lateral view of AMF 125149, Loc. 2, 5.7m. L, M. *Ozarkodina cadiaensis* Bischoff 1986. L. Pa element, inner lateral view of AMF 125150, Loc. 2, 0.1m. M. Pb element, lateral view of AMF 125151, Loc. 2, 0.1m. N, O *Ozarkodina australensis* Bischoff, 1986. Pa elements, lateral views of AMF 125152 and AMF 125153, respectively, Loc. 2, 0.1m.

of the former, however, is relatively larger than the latter.

Simpson (2003) provided the description and reconstruction of this taxon. It is geographically widespread and restricted to the interval from the Ludlow *siluricus* Zone through to the earliest Devonian *woschmidtii* Zone.

Ozarkodina remscheidensis costeinhornensis

(Walliser, 1964)

Fig. 8, G.

For synonymy see Simpson & Talent (1995), supplemented by Mawson et al. (2003).

Remarks. This taxon has been discussed by Simpson & Talent (1995), *inter alia*, and additional interpretations concerning the phylogeny of the broader group were given by Mawson et al. (2003). A single Pa element was recovered from the Pyle's limestone unit. Despite one larger denticle on the anterior process, this poorly preserved element is characterised by a row of denticles of approximately uniform height, each being relatively perpendicular to the blade, and the typical widely flared basal cavity. It therefore readily fits within the variation of the populations of the subspecies from Cellon as illustrated by Walliser (1964, Pl. 20, figs 7, 8, 12–16, 19–25) and revised by Klapper & Murphy (1974). This is a broader view of the taxon than utilised by Jeppsson (1989).

***Distomodus stauognathoides* (Walliser, 1964)**

Fig. 6, G, I, M–N.

For synonymy see Simpson (1999: 189) and add the following:

Distomodus stauognathoides (Walliser) – Cockle 1999: 120, pl. 1., fig. 18. – Talent & Mawson 1999: pl. 3, figs 3–4, 9–15. – Rickards et al. 2001: Fig. 2, h–l. – Farrell 2002: Fig. 4, D–F, H, I, K. – Zhang & Barnes 2002: 13–15, Fig. 14.1–14.7.

Remarks. A single Sc element was obtained in this study. Although the ramiform complex of the genus *Distomodus* shows similarities across species, particularly in the symmetry transition series, we consider this element most probably represents *D. stauognathoides* because of the age of the interval. It is almost identical in morphology to that illus-

trated by Rickards et al. (2001: Fig. 4i.) from the *amorphognathoides* Zone, the latter was recovered with the distinctive platform element.

?*Icriodus* sp. a Simpson

Fig. 8E.

?*Icriodus* sp. n. A Simpson 1998: 160, pl. 3, figs 12–19.

Remarks. This single element bears strong similarity to Late Silurian elements recovered from the Jack Formation in north Queensland (Simpson 1998). Whilst the element has the typical triangular basal structure typical of Sa elements, this example is slightly asymmetrical and may possibly represent an Sa/Sb transitional form.

***Pseudobelodella silurica* Armstrong, 1990**

Fig. 7, I–J.

For synonymy see Simpson & Talent (1995: 176).

Remarks. The single element is erect with numerous fused apically inclined denticles. It has a close resemblance to the aq element of this taxon. Despite the fact that Armstrong (1990) differentiated this genus from *Belodella* by the presence of the heeled sym p element, the morphology of the single aq element recovered in this study allows identification with some confidence.

***Panderodus* ?n. sp.**

Fig. 8J.

Remarks. The single element described above has a number of distinctive features not typically noted in populations of *Panderodus*. It may therefore represent a new species. It is illustrated and kept in open nomenclature for comparative purposes. Other *Panderodus* elements obtained in this study have not been investigated in detail.

APPENDIX: NOTES ON SAMPLED LOCALITIES

1. This, the most productive for conodonts of the limestone occurrences sampled, outcrops boldly on both flanks of the Mitta Mitta River about 260–320 m upstream from its junction with Wombat Creek (Whitelaw 1954: fig. 2^E). It was interpreted

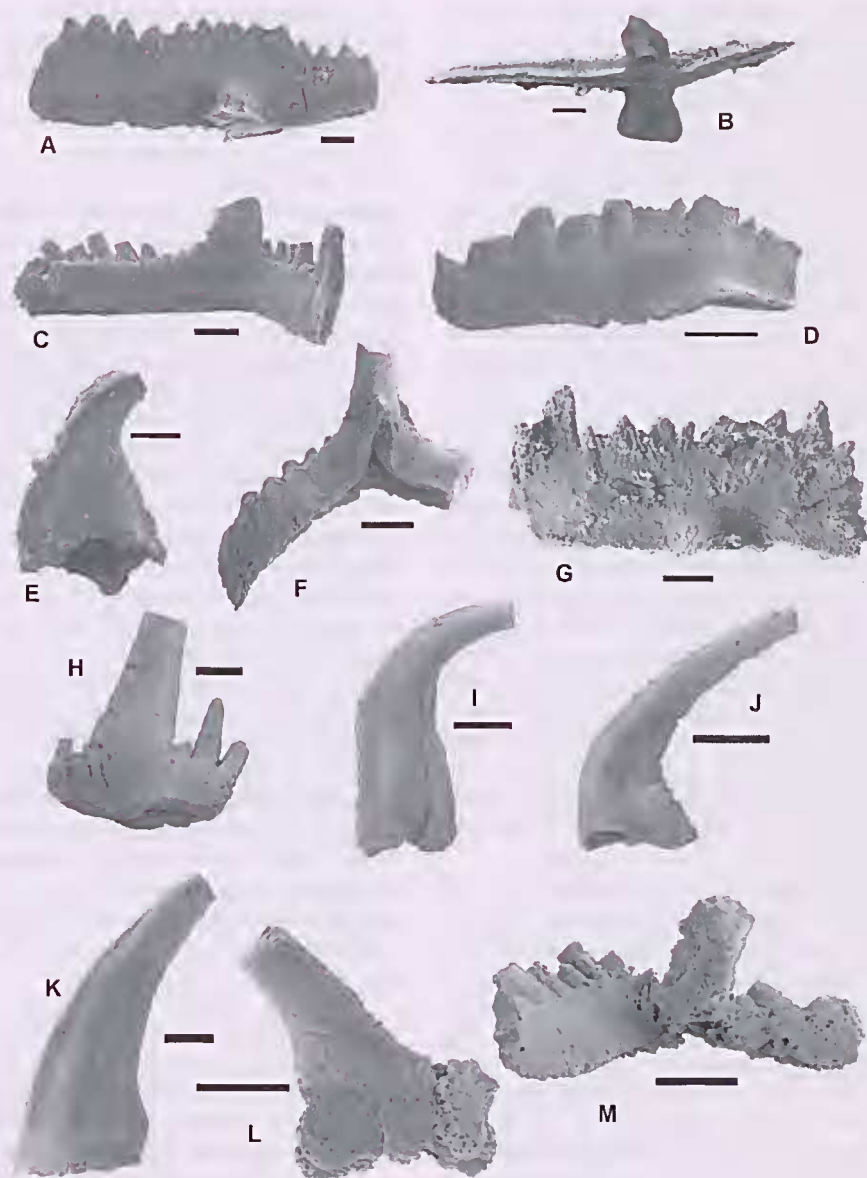


Fig. 8. Late Silurian (late Ludlow to mid-Prídoli) conodonts from Pyle's limestone deposit, 4.5 km north-northeast of Benambra, and Late Silurian conodonts from limestone clasts, "Wibenduck Limestone", Martins Creek-Sardine Creek Saddle, eastern Victoria (for localities see Appendix, Fig. 1, and VandenBerg et al., 1998b, 1992).

A-B. *Ozarkodina martinsoni auriformis* Simpson 2003, Pa element, lateral and lower view respectively of AMF 125154, Loc. 5. C-D. *Ozarkodina excavata excavata* (Branson & Mehl 1933). C. Se element, inner lateral view of AMF 125155, Loc. 5. D. Pa element, outer lateral view of AMF 125156, Loc. 5. E. *?Icriodus* sp. a Simpson 1998, Sa/Sb element, posterior view of AMF 125157, Loc. 5. F. *Ozarkodina excavata excavata* (Branson & Mehl 1933), Sa element (incomplete), inner lateral view of AMF 125158, Loc. 5. G. *Ozarkodina remscheidensis costeinhoruensis* (Walliser 1964), Pa element, lateral view of AMF 125159, Loc. 4. H. *Ozarkodina excavata excavata* (Branson & Mehl 1933) fragmentary ?Sb element, inner lateral view of AMF 125160, Loc. 4. I. *Panderodus* sp., lateral view of AMF 125161, Loc. 4. J. *Panderodus* ?n. sp., lateral view of AMF 125162, Loc. 4. K. *Panderodus* sp., lateral view of AMF 125163, Loc. 4. L. Indeterminate fragment, AMF 125164, Loc. 4. M. *Ozarkodina* sp., fragmentary Sb element, AMF 125165, Loc. 4.

(VandenBerg et al. 1998b) as two bodies, one within the Toaks Creek Conglomerate, the other at the boundary between the Toaks Creek Conglomerate and the overlying Gibbo River Siltstone. We prefer Whitelaw's (1954: 26) interpretation that these are outcrops of the same limestone body on opposite sides of the Mitta Mitta River. Our sampled section commenced at the base of the limestone (= Whitelaw 1954, Fig. 2^E; = 'Lower Mitta limestone' of VandenBerg et al. 1998a = base of the Gibbo River Siltstone) on the east flank of the Mitta Mitta River arm of Dartmouth Dam at grid reference 5589₅,59318₀ on Benambra 1:50,000 sheet 8424-3.

2. Sampled section (11 samples) through Brammall Bluff (Whitelaw 1954, Fig. 3^B; = 'Hairpin limestone' of VandenBerg et al. 1998a); interpreted by VandenBerg et al. (1998a) as being in the Undowah Siltstone on the north flank of the Gibbo River commencing at grid reference 5607₉₆,59314₆₃ on Benambra 1:50,000 sheet 8424-3. The start of the sampled section is 75 m (across strike) above the base of an interval of generally massive, yellow-buff-weathering dolomitic limestone or dolomite. The section extends through 37 m of well-bedded siltstones with slaty carbonates (often iron-rich), thin-bedded rather bioelastic limestones and nodular limestones (subordinate to siltstones), and is followed by a further 25 m with buff- to yellow-weathering dolomitic olistoliths (largest c. 5 m) exhumed from upslope.

3. Spot sample from the southeast end of 'Quart Pot limestone' of VandenBerg et al. (1998a) (= Whitelaw 1954, Fig. 2^D) at grid reference 5568₄₅,59326₃ on Benambra 1:50,000 sheet 8424-3. Repeated sampling of the 'Quart Pot limestone' (Whitelaw 1954, figs. 2^C and 2^D) at grid reference 5565₅,59327₅ (limestone with pentamerids) and 5565₃,59327₄, and the nearby 'Toak's Gap limestone' in the vicinity of 5540,5935₇, all on Dart 1:50,000 sheet 8424-4, failed to produce conodonts. In both cases contacts with the underlying conglomerates and arenites and with the overlying mudstones are obscured by alluvials or soil.

4. Spot samples from Pyle's limestone deposit (Whitelaw 1954: fig. 3^D; Talent et al. 1975; Simpson & Talent 1995; VandenBerg et al. 1998a) at grid reference 5644₈,59141₀ on Benambra 1:50,000 sheet 8424-3 where there are poor exposures of metamorphosed calcareous siltstones and arenites with minor thin bands of limestone. This occurrence was interpreted (VandenBerg et al. 1998a: 104) as overlying Pinnak Sandstone (Early Ordovician).

5. Spot samples of "Wibenduek Limestone" from float and from a small quarry outcropping beside the Seanlon Creek Track on Bendoe 1:100,000 sheet 8623 at grid reference 394,557.

6. Samples from the 'Lower Gibbo limestone' (a body we agree with VandenBerg et al. 1998a, is an olistolith) at 5597₅,59317₅, from the 'Silver Flat limestone' in the vicinity of 5612,59308 (several samples), from the counterpart of the 'Lower Mitta limestone' of VandenBerg et al. (1998a; = Whitelaw 1954, Fig. 2^F) but on the west flank of the Mitta Mitta River arm of Dartmouth Dam, and from a sampled stratigraphic section through the 'Meanders 3 limestone' of VandenBerg et al. (1998a) in the vicinity of 5592,59292, all on Benambra 1:50,000 sheet 8424-3, also failed to produce conodonts.

7. A superbly exposed limestone and calcareous mudstone sequence (Whitelaw 1954: fig. 2^F) outcrops in a cliff on the right flank of the Mitta Mitta River about 3.6 km upstream from its junction with Wombat Creek. It may be as much as 1000 m stratigraphically higher in the Tongaro Siltstone than the 'Lower Mitta limestone', but the possibility of faulting (Fig. 3) between it and the 'Lower Mitta limestone' prevents accurate assessment of the intervening thickness. It too shows very gradual transition from massive through bedded limestone to calcareous mudstones — again a relationship we interpret as indicating a probably autochthonous sequence rather than an olistolith. Unfortunately this occurrence — with tabulate corals including halysitids (Chapman 1920) — has so far failed to produce conodonts.

ACKNOWLEDGEMENTS

We pay tribute to Fons VandenBerg and co-workers for the major advances they have made in understanding the geology of vast areas of the most rugged parts of eastern Victoria, elegantly summarised in VandenBerg et al. (2000). We are grateful to Fons for having generously made available a copy of a manuscript embodying his views on the age, depositional environments, and tectonic setting of the Silurian limestones of eastern Victoria. We are also grateful to John Webb who gave us a collection of conodonts from the "Wibenduek Limestone", to Anita Harris of the U.S. Geological Survey for making available to us a colour-standard set of conodonts for making our CAI determinations, and to Greg Edgecombe, Lennart Jeppsson and Ian

Perceval for attentively reading and making helpful comments on our manuscript. The drafting is by our friend Dean Oliver.

REFERENCES

- ALDRIDGE, R. J. & SCHÖNLAUB, H. J., 1989. Conodonts. In *A global standard for the Silurian System*, 247–279. In C. H. Holland & M. G. Bassett, eds, National Museum of Wales, Geological Series 9. Cardiff.
- ALLEN, R. L., 1987. *Subaqueous volcanism, sedimentation and the geological setting of Zn–Cu–Pb massive sulphide deposits, Benambra, S.E. Australia*, 284 p. Ph.D. thesis, Department of Earth Sciences, Monash University, Melbourne.
- ALLEN, R. L., 1988. Limestone Creek Graben. In *Geology of Victoria*, 92. In J. G. Douglas & J. A. Ferguson, eds, Victorian Division, Geological Society of Australia Inc.
- ALLEN, R. L., 1991. *Limestone Creek area 1:50 000 geological map, edition 2*. Geological Survey of Victoria, Melbourne.
- ALLEN, R. L., 1992. Reconstruction of the tectonic, volcanic, and sedimentary setting of strongly deformed Zn–Cu massive sulfide deposits at Benambra, Victoria. *Economic Geology* 87: 825–854.
- ANDREWS, E. C., 1938. The structural history of Australia during the Palaeozoic. (The stabilization of a continent). *Journal and Proceedings of the Royal Society of New South Wales* 71: 118–187.
- ARMSTRONG, H. A., 1990. Conodonts from the Upper Ordovician–Lower Silurian carbonate platform of north Greenland. *Grønlands Geologiske Undersøgelse* 159: 1–151.
- BARCA, S., FERRETTI, A., MASSA, P. & SERPAGLI, E., 1992. The Hercynian Arburese tectonic unit of SW Sardinia new stratigraphic unit and structural data. *Rivista Italiana di Paleontologia e Stratigrafia* 98 (2): 119–136.
- BIRCH, W. D., HENRY, D. A. & PRING, A., 1995. A new occurrence of Mrazekite from Benambra, Victoria, Australia. *The Mineralogical Record* 26: 107–113.
- BISCHOFF, G. C. O., 1986. Early and Middle Silurian conodonts from midwestern New South Wales. *Courier Forschungsinstitut Senckenberg* 89: 1–337.
- BOLGER, P., 1982. Ordovician and Silurian stratigraphy and structure in the Wombat Creek–Benambra area, northeast Victoria. *Proceedings of the Royal Society of Victoria* 94: 35–47.
- BRIME, C., TALENT, J. A. & MAWSON, R., 2003. Low grade metamorphism in the Palaeozoic sequences of the Townsville hinterland of northeastern Australia. *Australian Journal of Earth Sciences* 50: 751–767.
- BROWNE, W. R., 1947. A short history of the Tasman Geosyncline of eastern Australia. *Science Progress* 140: 623–637.
- CALNER, M. & JEPSSON, L., 2003. Carbonate platform evolution and conodont stratigraphy during the Middle Silurian Mulde Event, Gotland, Sweden. *Geological Magazine* 140: 173–203.
- CAREY, S. P. & BOLGER, P. F., 1995. Conodonts of disparate Lower Devonian zones, Wilson Creek Shale, Tyers–Walhalla area, Victoria, Australia. *Alcheringa* 19: 73–86.
- CHAPMAN, F., 1912. Reports on fossils. Silurian and Devonian fossils from the Mitta Mitta district, northeast Victoria. *Records of the Geological Survey of Victoria* 3: 215–217.
- CHAPMAN, F., 1920. Palaeozoic fossils of eastern Victoria. Part IV. *Records of the Geological Survey of Victoria* 4: 175–194.
- COCKLE, P., 1999. Conodont data in relation to time, space and environmental relationships in the Silurian (Late Llandovery–Ludlow) succession at Boree Creek (New South Wales, Australia). *Abhandlungen der Geologischen Bundesanstalt* 54: 107–133.
- COLLINS, W. J., & HOBBS, B. E., 2001. What caused the Early Silurian change from mafic to silicic (S-type) magmatism in the eastern Lachlan Fold Belt? *Australian Journal of Earth Sciences* 48: 25–51.
- COLQUHOUN, G. P., 1995. Early Devonian conodont faunas from the Capertee High, NE Lachlan Fold Belt, southeastern Australia. *Courier Forschungsinstitut Senckenberg* 182: 347–369.
- CONAGHAN, P. J., MOUNTJOY, E. W., EDGECOMBE, D. R., TALENT, J. A. & OWEN, D. E., 1976. Nubigrign algal reefs (Devonian), eastern Australia: Allochthonous blocks and megabreccias. *Geological Society of America Bulletin* 87: 515–530.
- COOPER, B. J., 1977. Preliminary report on conodonts from the Wombat Creek Group,

- north-eastern Victoria. *South Australian Department of Mines Report* 77/139 (unpublished).
- CORRADINI, C., FERRETTI, A., SERPAGLI, E. & BARCA, S., 1998. The Ludlow–Pridoli section Genna Ciureciu, west of Silius. *Giornale di Geologia*, series 3a, 60, Special Issue, ECOS VII–Sardinia Guide Book, 112–118.
- CORRADINI, C. & SERPAGLI, E., 1999. A Silurian conodont biozonation from late Llandovery to end Pridoli in Sardinia (Italy). *Bollettino della Società Paleontologica Italiana* 37(2–3): 255–273.
- CROOK, K. A. W., BEIN, J., HUGHES, R. J. & SCOTT, P. A., 1973. Ordovician and Silurian history of the southeastern part of the Lachlan Geosyncline. *Journal of the Geological Society of Australia* 20: 113–138.
- EPSTEIN, A. G., EPSTEIN, J. B., & HARRIS, L. D., 1977. Conodont Colour Alteration — an index to organic metamorphism. *United States Geological Survey Professional Paper* 995: 1–27.
- ERIKSSON, M., 2001. Silurian ramphoprionid polychaetes from Gotland, Sweden. *Journal of Paleontology* 75: 993–1015.
- FARRELL, J. R., 2002. Reworked Silurian and Ordovician conodonts from the Late Devonian Catombal Group, central western New South Wales. *Aleheringa* 26: 37–48.
- FERGUSON, W. H., 1899. Report on collection of fossils, etc., from Wombat Creek. *Geological Survey of Victoria Monthly Progress Report* 3: 17.
- FERRETTI, A., CORRADINI, C., & SERPAGLI, E., 1998. Wenlock–Ludlow conodonts from Perd'c Fogu (Fluminimaggiore). *Giornale di Geologia*, series 3a, 60, Special Issue, ECOS VII–Sardinia Guide Book, 156–167.
- FOSTER, D. A. & GRAY, D. R., 2000. The structure and evolution of the Lachlan Fold Belt (Orogen) of eastern Australia. *Annual Review of Earth and Planetary Sciences* 28: 47–80.
- FOSTER, D. A., GRAY, D. R. & BUCHER, M., 1999. Chronology of deformation within the turbidite-dominated Lachlan Orogen: implications for the tectonic evolution of eastern Australia and Gondwana. *Tectonics* 18: 452–485.
- FOSTER, D. A., GRAY, D. R. & VANDENBERG, A. H. M., 2000. Discussion and Reply: Timing of orogenic events in the Lachlan Orogen. *Australian Journal of Earth Sciences* 47: 813–822.
- FUREY-GREIG, T., 1995. The “Nemingha” and “Loomberah” limestones (Early Devonian; Emsian) of the Nemingha–Nundle area, northern New South Wales: conodont data and inferred environments. *Courier Forschungsinstitut Senckenberg* 182, 217–233.
- GRAY, D. R. & FOSTER, D. A., 1997. Orogenic concepts — application and definition: Lachlan Fold Belt, eastern Australia. *American Journal of Science* 297: 859–891.
- GRAY, D. R. & FOSTER, D. A., 1998. Character and kinematics of faults within the turbidite-dominated Lachlan Orogen: implications for the tectonic evolution of eastern Australia. *Journal of Structural Geology* 20: 1691–1720.
- GRAY, D. R. & FOSTER, D. A., 1999. Character and kinematics of faults within the turbidite-dominated Lachlan Orogen: implications for the tectonic evolution of eastern Australia: Reply. *Journal of Structural Geology* 22: 1529–1535.
- GRAY, D. R., FOSTER, D. A. & BUCHER M., 1997. Recognition and definition of orogenic events in the Lachlan Fold Belt. *Australian Journal of Earth Sciences* 44: 489–581.
- HARRIS, A. G. 1979. Conodont color alteration, and organo-mineral metamorphic index, and its application to Appalachian Basin geology. In *Aspects of diagenesis*, P. A. Scholle & P. R. Schlager, eds, *Society of Economic Paleontologists and Mineralogists, Special Publication* 26: 3–16.
- HARRIS, A. G. 1981. Color and alteration: an index to organic metamorphism in conodont elements, W56–W60. In: Clark D. L. and 10 others, *Treatise on Invertebrate Paleontology, Part W, Miscellaneous, Supplement 2*, Conodonts. Geological Society of America, Boulder, and University of Kansas, Lawrence.
- JEPPSSON, L., 1989. Latest Silurian conodonts from Klönk. *Geologica et Palaeontologica* 23: 21–37.
- JEPPSSON, L., 1997. A new latest Telychian, Sheinwoodian and Early Homerian (Early Silurian) Standard Conodont Zonation.

- Transactions of the Royal Society of Edinburgh, Earth Sciences* 88: 91–114.
- KLAPPER, G. & MURPHY, M. A., 1974. Silurian–Lower Devonian conodont sequence in the Roberts Mountains Formation of central Nevada. *University of California Publications in the Geological Sciences* 115: 62 pp., 12 pls.
- LINK, A. & DRUCE, E. C., 1972. Ludlovian and Gedinian conodont biostratigraphy of the Yass Basin, New South Wales. *Bulletin of the Bureau of Mineral Resources, Geology and Geophysics* 134: 136 pp., 12 pls.
- MÄNNIK, P., 1998. Evolution and taxonomy of the Silurian conodont *Pterospirifer*. *Palaeontology* 41: 1001–1050.
- MÄNNIK, P. & ALDRIDGE, R. J., 1989. Evolution, taxonomy and relationships of the Silurian conodont *Pterospirifer*. *Palaeontology* 32: 893–906.
- MAWSON, R., MOLLOY, P. D., SIMPSON, A. J. & TALENT, J. A., 2003. Latest Silurian and Early Devonian conodonts from Nowshera, NWFP, Pakistan. *Courier Forschungsinstitut Senckenberg* 245: 83–105.
- MAWSON, R., PANG, D. & TALENT, J. A., 1998. G. J. Hinde's (1899) Devonian radiolarians from the Tamworth area, north-eastern New South Wales: stratigraphic and chronological context. *Proceedings of the Royal Society of Victoria* 109: 233–256.
- MAWSON, R. & TALENT, J. A., 1994. Age of an Early Devonian carbonate fan and isolated limestone clasts and megacrysts, east-central Victoria. *Proceedings of the Royal Society of Victoria* 106: 31–70.
- MEINERT, L. D., 1992. Skarns and skarn deposits. *Geoscience Canada* 19: 145–152.
- MILLER, C. G. 1995. Ostracode and conodont distribution across the Ludlow/Pridoli boundary of Wales and the Welsh Borderland. *Palaeontology* 38: 341–384.
- PACKHAM, G. H. (ed.) 1969. The geology of New South Wales. *Journal of the Geological Society of New South Wales* 16: 1–654.
- PACKHAM, G. H., PERCIVAL, I. G. & BISCHOFF, G. C. O. 1999. Age constraints on strata enclosing the Cadia and Junction Reefs ore deposits of central New South Wales, and tectonic implications. *Quarterly Notes of the Geological Survey of New South Wales* 110: 1–12.
- PERCIVAL, I. G., 1998. The age of the Nandillyan and Narragall limestones, Molong High, central western New South Wales. *Geological Survey of New South Wales, Quarterly Notes* 107: 12–19.
- RAMSAY, W. R. H. & VANDENBERG, A. H. M., 1986. Metallogeny and tectonic development of the Tasman Fold Belt System in Victoria. *Ore Geology Reviews* 1: 213–257.
- REED, A. R., 2001. Pre-Tabberabberan deformation in eastern Tasmania: a southern extension of the Benambran Orogeny. *Australian Journal of Earth Sciences* 48: 785–796.
- REJEBIAN, V. A., HARRIS, A. G. & HUEBNER, J. S., 1987. Conodont colour and textural alteration: An index to regional metamorphism. *Geological Society of America Bulletin* 99: 471–479.
- RICKARDS, R. B., PERCIVAL, I. G., SIMPSON, A. J. & WRIGHT, A. J., 2001. Silurian biostratigraphy of the Cadia area, south of Orange, New South Wales. *Proceedings of the Linnean Society of New South Wales* 123: 173–191.
- SCHEIBNER, E. 1997. Geology of New South Wales — synthesis. Vol. 2, Geological evolution, 666 p. New South Wales Department of Mineral Resources, Sydney.
- SERPAGLI, E., CORRADINI, C. & FERRETTI, A., 1998. Conodonts from a Ludlow–Pridoli section near the Silius village. *Giornale di Geologia*, series 3a, 60, Special Issue, ECOS VII-Sardinia Guide Book, 104–111.
- SIMPSON, A. J., 1998. Apparatus structure of the latest Silurian to early Devonian conodont *Icriodus woschmidti hesperius* Klapper et Murphy, and some comments on phylogeny. *Palaeontologia Polonica* 58: 153–169.
- SIMPSON, A. J., 1999. Early Silurian conodonts from the Quinton Formation of the Broken River region, (north-eastern Australia). *Abhandlungen der Geologischen Bundesanstalt* 54: 181–199.
- SIMPSON, A. 2003. A new subspecies of the conodont genus *Ozarkodina* and its correlative value. *Courier Forschungsinstitut Senckenberg* 245: 75–82.
- SIMPSON, A. J., BELL, K. N., MAWSON, R., & TALENT, J. A., 1993. Conodonts and foraminifers from the late Ludlow (Late Silurian) at Cowombat, south-eastern Australia. *Aus-*

- tralasian Association of Palaeontologists, Memoir 15: 141–159.*
- SIMPSON, A. J. & TALENT, J. A., 1995. Silurian conodonts from the headwaters of the Indi (upper Murray) and Buchan rivers, south-eastern Australia, and their implications. *Courier Forschungsinstitut Senckenberg* 182: 79–215.
- SIMPSON, A. J., & TALENT, J. A., 1996. Middle Palaeozoic orogenic events in the southern Lachlan Fold Belt: age constraints from conodont data. *Geological Society of Australia Abstracts* 41: 396.
- SLOAN, T. R., TALENT, J. A., MAWSON, R., SIMPSON, A. J., BROCK, G. A., ENGELBRETSSEN, M. J., JELL, J. S., AUNG, A. K., PEFFENRITTER, C., TROTTER, J. & WITHNALL, I. W., 1995. Conodont data from Silurian–Middle Devonian carbonate fans, debris flows, allochthonous blocks and adjacent autochthonous platform margins: Broken River and Camel Creek areas, north Queensland, Australia. *Courier Forschungsinstitut Senckenberg* 182: 1–77.
- STIRLING, J., 1887. Second progress report on preliminary geological traverse of the western boundary of the County of Benambra. *Quarterly Reports of the Mining Registrars for the Quarter ended December 1887, Department of Mines, Victoria*, 75–77.
- STIRLING, J., 1888a. Geological structure of the country between Orbost and Hutton's Camp, on the Yalma Creek. *Mining Regulations Report, Quarter ending 31 March 1888, Geological Survey, Victoria*, 87–88.
- STIRLING, J., 1888b. Appendix D. Preliminary notes on the geology of the Wombat Creek valley, its caves and silver lodes. *Reports of the Mining Surveyors and Registrars, Quarter ending 30th September 1888, Department of Mines, Victoria*, 78–80.
- TALENT, J. A., 1959. Notes on Middle Palaeozoic stratigraphy and diastrophism in eastern Victoria. *Mining and Geological Journal (Victoria)* 6 (3): 57–58.
- TALENT, J. A., BERRY, W. B. N. & BOUCOT, A. J., 1975. Correlation of the Silurian rocks of Australia, New Guinea and New Zealand. *Geological Society of America Special Paper* 150: 108 pp.
- TALENT, J. A. & MAWSON, R., 1999. North-eastern Molong Arch and adjacent Hill End Trough (eastern Australia): Mid-Palaeozoic conodont data and implications. *Abhandlungen der Geologischen Bundesanstalt* 54: 49–105.
- TALENT, J. A., MAWSON, R. & SIMPSON, A. J., 2003a. Silurian of Australia and New Guinea. In *Silurian Lands and Seas — Paleogeography outside of Laurentia*, E. Landing & M. E. Johnson, eds, *New York State Museum Bulletin* 493: 181–220.
- TALENT, J. A., MAWSON, R. & SIMPSON, A. J., 2003b. The “lost” Early Ordovician–Devonian Georgetown Carbonate Platform of north-eastern Australia. *Courier Forschungsinstitut Senckenberg* 242: 71–79.
- TALENT, J. A., MAWSON, R., SIMPSON, A. J. & BROCK, G. A., 2002. Ordovician–Carboniferous of the Townsville Hinterland: Broken River and Camel Creek regions, Burdekin and Clarke River Basins. Macquarie University Centre for Ecostratigraphy and Palaeobiology Special Publication 1: 82 pp.
- TAYLOR, C. D., 1984. Structure and stratigraphy of the Yalmy Creek area, 41 pp. BSc (Hons) dissertation, Department of Earth Sciences, Melbourne University.
- THOMAS, D. E., 1954. Foreword [to Whitelaw, H. S., 1954, q.v.]. *Mining and Geological Journal (Victoria)* 5 (3): 23.
- VANDENBERG, A. H. M., 1988. Silurian–Middle Devonian. In *Geology of Victoria*, I. G. Douglas & J. A. Ferguson, eds, Geological Society of Australia, Victorian Division, Melbourne, 103–146.
- VANDENBERG, A. H. M., 1999. Timing of orogenic events in the Lachlan Orogen. *Australian Journal of Earth Sciences* 46: 691–701.
- VANDENBERG, A. H. M., BOLGER, P. F. & O'SHEA, P. J., 1984. Geology and mineral exploration of the Limestone Creek area, northeast Victoria. *Geological Survey Report, Department of Minerals and Energy Victoria* 72, 59 pp.
- VANDENBERG, A. H. M., HENDRICKX, M. A., WILLMAN, C. E., MAGART, A. P. M., SIMONS, B. A. & RYAN, S. M., 1998a. Benambra 1:100 000 map area geological report. *Geological Survey Report, Department of Natural Resources and Environment Victoria*, 114, 279 pp.
- VANDENBERG, A. H. M., MAGART, A. P. M., SIMONS, B. A., WILLMAN, C. E. & HENDRICKX, M. A., 1998b. 1:50 000 geological map,

- Benambra 8424-3. *Geological Survey of Victoria, Department of Natural Resources and Environment Victoria*.
- VANDENBERG, A. H. M., NOTT, R. J. & GLEN, R. A., 1992. Bendoc 1:100, 000 Map Geological Report. *Geological Survey Report, Department of Energy & Minerals, Victoria* 90, 121 pp.
- VANDENBERG, A. H. M., WILLMAN, C. E., MAHER, S., SIMONS, B. A., CAYLEY, R. A., TAYLOR, D. H., MORAND, V. J., MOORE, D. H. & RADKOVIC, A. 2000. *The Tasman Fold Belt system in Victoria*, 492 p. Geological Survey of Victoria, Special Publication, Melbourne.
- WALLISER, O.H., 1964. Conodonten des Silurs. *Abhandlungen des hessischen Landesamtes für Bodenforschung* 41, 1–106.
- WALLEY, A. M., STRUSZ, D.L. & YEATES, A. N., 1990. *Palaeogeographic Atlas of Australia, vol. 3, Silurian*. Bureau of Mineral Resources, Geology and Geophysics, Canberra, Australia, 27 pp.
- WHITELAW, H. S., 1954. Some limestone and marble deposits of east Gippsland. *Mining and Geological Journal (Victoria)* 5 (3): 23–33.
- WILLMAN, C. E., MORAND, V. J., HENDRICKX, M. A., VANDENBERG, A. H. M., HAYDON, S. J. & CARNEY, C., 1999. The geology and prospectivity of the Omeo 1:100 000 map area, eastern Victoria. *Geological Survey Report, Department of Natural Resources and Environment Victoria* 118 pp.
- ZHANG, S. & BARNES, C. R., 2002. A new Llandovery (Early Silurian) conodont biozonation and conodonts from the Beeseie, Merrimaek, and Gun River formations, Anticosti Island, Quebec. *Journal of Paleontology* 76, (Supplement to No 2; Paleontological Society Memoir 57), 46 pp.